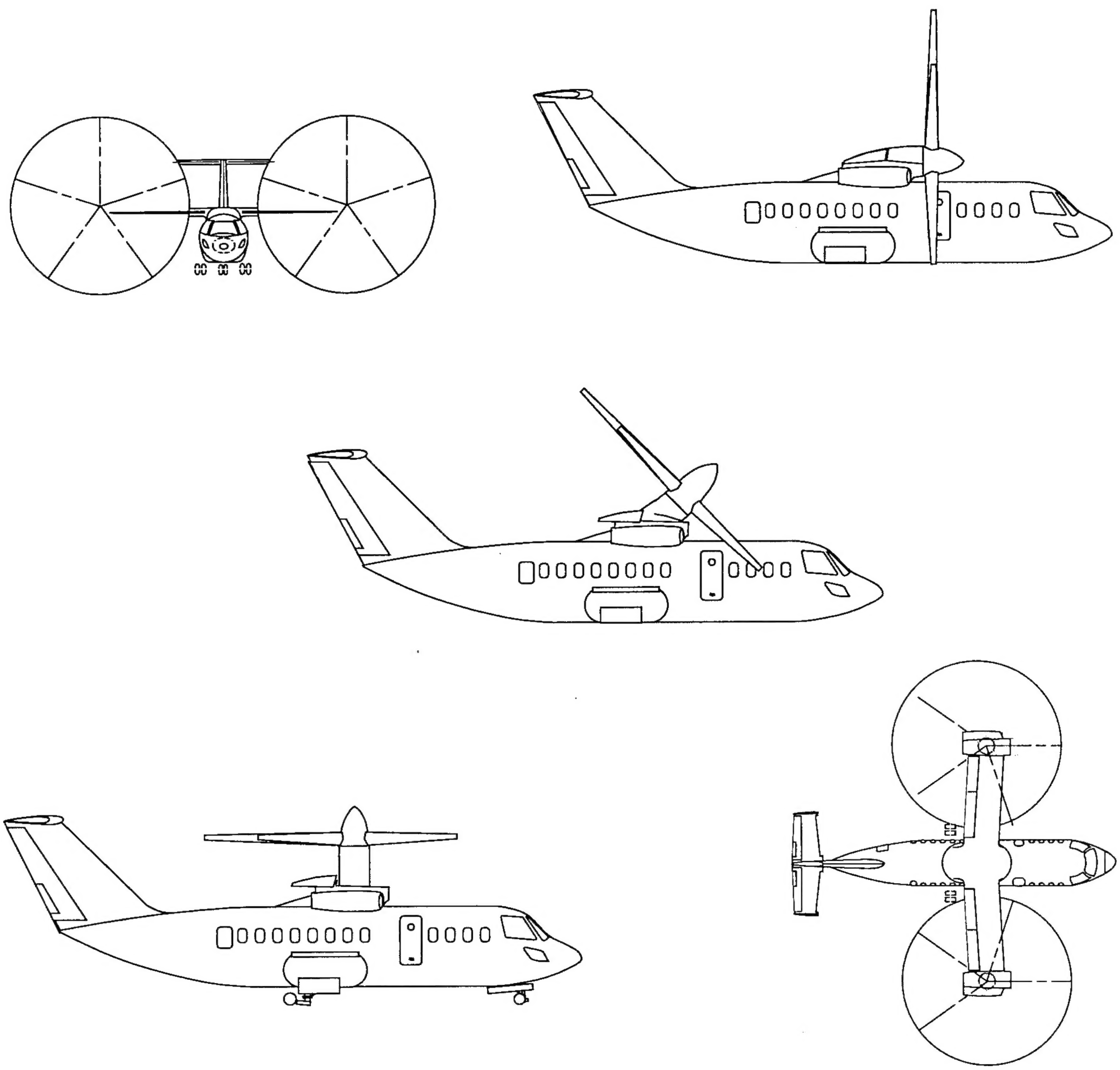
Civil Tiltrotor Development Advisory Committee

Report to Congress

in accordance with PL102-581

Volume 1 Final Report

December 1995



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16. Abstract

Under public law (PL102-581), the U.S. Congress directed the Secretary of Transportation to establish a Civil Tiltrotor Development Advisory Committee (CTRDAC). The committee was directed to examine the costs, technical feasibility, and economic viability of developing civil tiltrotor (CTR) aircraft.

The CTRDAC found that the CTR is technically feasible, that it could be economically viable and operate profitable without government subsidies in heavily traveled corridors, and that it could provide significant societal benefits.

The CTRDAC recommended that a public/private partnership be created to address CTR institutional, infrastructure, and coordination issues; that an integrated aircraft and infrastructure research, development, and demonstration program be conducted over 10 years with $600 million in Government/industry cost sharing; and that work be accelerated on regulatory and certification issues, including safety and environmental standards and changes in the air traffic control system.

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U.S. Department of Transportation
Office of the Secretary of Transportation

Assistant Secretary

400 Seventh St., S.W.
Washington, D.C. 20590

December 29, 1995

The Honorable Albert Gore, Jr.
President of the Senate
Washington, D.C. 20510

Dear Mr. President:

It is my pleasure to transmit the report of the Civil Tiltrotor Development Advisory Committee (CTRDAC), required by Section 135 of the Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992 (P.L. 102-581). The Secretary of Transportation established the CTRDAC in accordance with P.L. 102-581. Its membership includes representation from a broad spectrum of private and public sector agencies, companies and associations, as well as the Department of Transportation, the National Aeronautics and Space Administration, and the Department of Defense.

The Committee has evaluated the technical feasibility and economic viability of developing civil tiltrotor (CTR) aircraft and a national system of infrastructure to support incorporation of tiltrotor technology into the national transportation system. It found that the CTR is technically feasible and under certain circumstances could be economically viable and operate profitably without government subsidies. Introduction of CTR for scheduled transportation service would depend upon overcoming a number of significant uncertainties and risks. One of the most important of these is the ability to locate vertiports at central city locations in large metropolitan areas, as well as suburban points close to major employment and economic centers. The successful completion of additional vehicle and infrastructure research would be required along with many interdependent decisions involving manufacturers, operators and various levels of government. In the Committee's view, the potential benefits, primarily delay reduction at congested airports and improved service to travelers, could be significant.

The report recommends expanding the existing CTR research program and the creation of a public/private partnership to address these institutional, infrastructure and coordination issues. The report recommends that research costs be shared by industry and government while aircraft development costs be the responsibility of industry. Infrastructure costs would be borne by system users and aircraft operators with local government

managing facility financing in a manner similar to current airport financing practices. Clearly, obtaining the significant Federal funding envisioned for the cooperative research, test and demonstration effort will be difficult in this time of budget stringency. Similarly, local funding for vertiport development is likely to be limited.

The report also recognizes that there may be other competing technologies for highly traveled transportation corridors and recommends that DOT initiate a multimodal study of options, including CTR, for increasing intercity transportation capacity.

As Chairman I can personally attest to the excellent qualifications and experience represented on the Committee and the dedication and commitment the members demonstrated over the course of the Committee's work. The report represents a general consensus of the CTRDAC membership, although individual Committee members had concerns with specific findings and recommendations. Although several members of the Committee are executives within the Administration, the report should not be interpreted as representing Administration policy. Copies of the report will be furnished to the Secretary of Transportation, Secretary of Defense, and the Administrator of NASA for consideration.

A report has also been sent to the Speaker of the House.

Sincerely,

Frank E. Kruesi

Frank E. Kruesi, Chair
Civil Tiltrotor Development
Advisory Committee

Enclosure

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* Dr. Janet Welsh Brown was unable to sign on to the final Committee report because she believes that continuing Federal support of the 40-passenger civil tiltrotor is not in the public interest at this time.

CTRDAC Final Report

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Executive Summary

Under Section 135 of the Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992 (PL102-581), the U.S. Congress directed the Secretary of Transportation to establish a Civil Tiltrotor Development Advisory Committee (CTRDAC). The committee was directed to examine the costs, technical feasibility, and economic viability of developing civil tiltrotor (CTR) aircraft; the integration of CTR aircraft into the national transportation system; and the resulting national economic benefits. The CTRDAC was charged with determining what further research and development and regulatory changes are needed to integrate CTR into the transportation system. The committee was also directed to investigate how CTR aircraft and related infrastructure development costs should be allocated between Government and industry.

Volume I of this report summarizes the work of the CTRDAC and its responses to the questions posed by Congress. Volume II is a technical supplement that covers the activities of the CTRDAC subcommittees in greater detail. A brief synopsis of CTRDAC findings and recommendations is shown below.

CTRDAC Findings

- CTR is technically feasible and can be developed by U.S. industry, but additional research and development and infrastructure planning are needed before industry can make a CTR production decision.
- Successful CTR introduction depends on overcoming significant uncertainties and risks. Decisions to manufacture CTRs, develop air and ground infrastructure, and operate services are interdependent with no one party controlling all resources needed to develop a CTR system.
- Vertiport siting is a critical factor in CTR system viability. Planning for CTR infrastructure development should be integrated into national and local transportation system planning.
- Under certain assumptions, a CTR system could be economically viable and operate profitably without government subsidies in heavily traveled corridors. CTR could attract a significant number of travelers willing to pay more for reduced overall trip time and greater convenience.
- CTR could produce significant societal benefits, reducing airport congestion, creating jobs, and having a positive impact on the balance of trade.

CTRDAC Recommendations

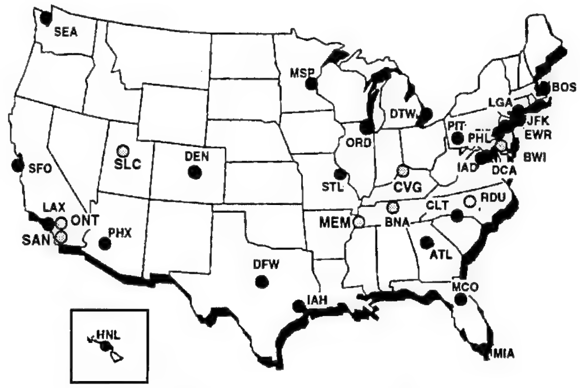
- Create a public/private partnership to address CTR institutional, infrastructure, and coordination issues with the Federal Government taking the lead to facilitate interdependent public/private decisions. Initiate infrastructure planning and design and obtain community commitment for vertiport development. Do not commit significant development resources until a CTR production decision is made.
- Proceed with an integrated CTR aircraft and infrastructure research, development, and demonstration program costing approximately $600 million over 10 years with costs shared by Government and industry.
- Continue and accelerate work on regulatory and certification issues, including safety and environmental standards and changes in the air traffic control system.
- The Department of Transportation should initiate a multimodal study of options, including CTR, to increase intercity transportation capacity.

Challenge for Transportation Planners

Intercity air and urban ground transportation passenger travel continues to grow more rapidly than the population. These growth rates are typically in the range of 2 to 3 percent per year depending on mode and location. Coupled with limited growth in transportation capacity, this increasing passenger demand has resulted in substantial delays to travelers.

In the aviation sector, congestion and resulting delays at major airports are a widespread cause for concern. Delays are projected to continue to increase despite improvements in air traffic control, increased use of larger aircraft, and airport capacity improvement projects. Other alternatives, such as introducing high-speed rail systems, do not appear to add sufficient capacity to the national transportation system to prevent congestion growth in the air transportation sector.

The development of a CTR system can be part of the solution to the problem of growing congestion at U.S. airports



- **Congested airports 1993 (actual)**
- **Additional congested airports 2003 (projected)**

Source: FAA Office of Policy and Plans
Note: 1) assumes no capacity improvements
2) Denver 1993 congestion alleviated by opening of new airport

The Tiltrotor Concept

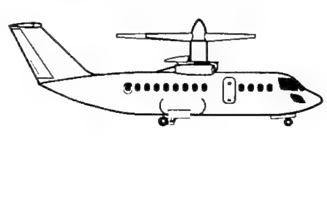
During the last four decades, the Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) have made large investments in research directed toward the development of aircraft capable of vertical take-off and landing with conversion to fixed-wing flight between origin and destination. The tiltrotor concept, in which the proprotors are rotated to a horizontal plane for take-off and landing, has become the preferred technology for achieving this capability.

A research tiltrotor aircraft, the XV-3, first flew in 1955. This was followed by the XV-15 which flew in 1977. These initial successes and the potential value of the concept stimulated further development.

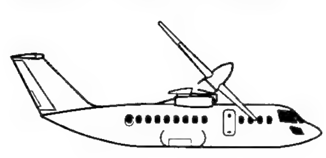
In the 1980s, the V-22 Osprey was developed for the DoD and full-scale development (FSD) aircraft were manufactured and flown. The V-22 program is currently in the engineering and manufacturing development (EMD) phase that began in October 1992 and will continue until late 1999.

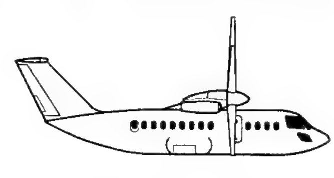
The CTR concept takes advantage of the ability of a tiltrotor aircraft to take off and land like a helicopter while cruising at the speed of a turboprop

With the wing tip nacelles pointing vertically, the tiltrotor operates likes a helicopter with side-by-side rotors.

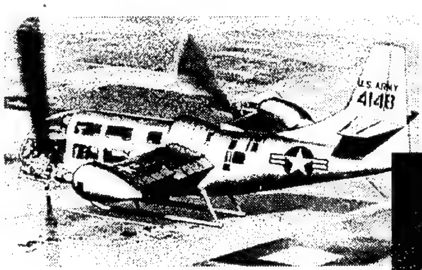


As the rotors are tilted forward, the tiltrotor accelerates with the wing gaining lift as speed increases.



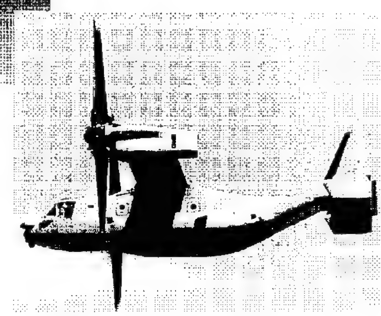


With the nacelles horizontal, the tiltrotor operates like a conventional turboprop airplane.



XV-3

XV-15



V-22

The objectives of the EMD phase are to translate the design of the V-22 FSD aircraft into a stable, producible, and cost-effective system while validating production processes and costs and demonstrating that the aircraft meets specifications. EMD flight tests will begin in late 1996. Initial limited production will begin in 1997 with full production expected after the successful completion of Government operational evaluations scheduled for 1999. The V-22 currently has well over 1,000 hours of flight testing.

Advances in lightweight structures, digital flight controls, and turboshaft engines have made the tiltrotor concept a candidate to provide commercial passenger service. The tiltrotor offers speed and range advantages over helicopters, while requiring substantially less area for landing sites than conventional passenger aircraft.

If a decision is made to develop a commercial CTR in the U.S, the largest market would be for a 40-passenger vehicle. A corporate size, with approximately 9 passengers, would have a significant but smaller market. The combined tiltrotor technical knowledge developed by U.S. industry, NASA, the Federal Aviation Administration (FAA), and the Department of Defense on the XV-3, XV-15, and V-22 tiltrotor programs would provide a sound foundation to initiate CTR development. By the time manufacturers are in a position to make a launch decision on production of a commercial service CTR, it is expected that there will be approximately 60,000 hours of flight time on V-22 production aircraft. This flight experience should provide important information on tiltrotor performance, reliability, and operation.

It should be noted that a European consortium, with government support, is working toward the development of a 30-passenger CTR aircraft and a 9-passenger CTR technology demonstrator. At the same time, other vertical flight alternatives are being explored both in the U.S. and overseas, including advanced helicopter technologies. Most of this work, however, is directed toward aircraft that are considerably smaller than the 40-passenger CTR considered in this report.

CTR—A New Transportation Alternative

The development of the V-22 and the ongoing NASA research and development effort has increased interest in the concept of a CTR to serve short-haul markets of 100 to 600 miles. The development of CTR technology and vertiports for tiltrotor operations could permit more rapid and convenient air travel between metropolitan areas.

This would allow passengers to depart from a facility closer to their point of origin and arrive at a facility closer to their ultimate destination, reducing their access/egress time and cost. For example, a passenger could depart from a suburban vertiport near home in Boston or Washington, D.C. and fly directly to a city-center vertiport in Manhattan, bypassing conventional airports in the Boston, Washington, D.C., and New York metropolitan areas.

While it will be possible to build various sizes of tiltrotor aircraft for the civil aviation market, the CTRDAC used a 40-passenger CTR as the baseline for its analysis. The 40-passenger size was chosen because analysis has indicated that it has the greatest initial potential to provide significant societal benefits. Although extensive regulatory and infrastructure concerns make it unlikely that the private sector could develop a CTR for scheduled service without Government leadership, a smaller CTR might be developed by the private sector for utility, executive travel, public service, emergency medical services, and other uses.

The 40-passenger CTR considered by the committee would be suited to three primary commercial markets:

- *Line-Haul Service*

Vertiport-to-vertiport operation between urban/suburban centers characterized by significant passenger demand.

- *Feeder Service*

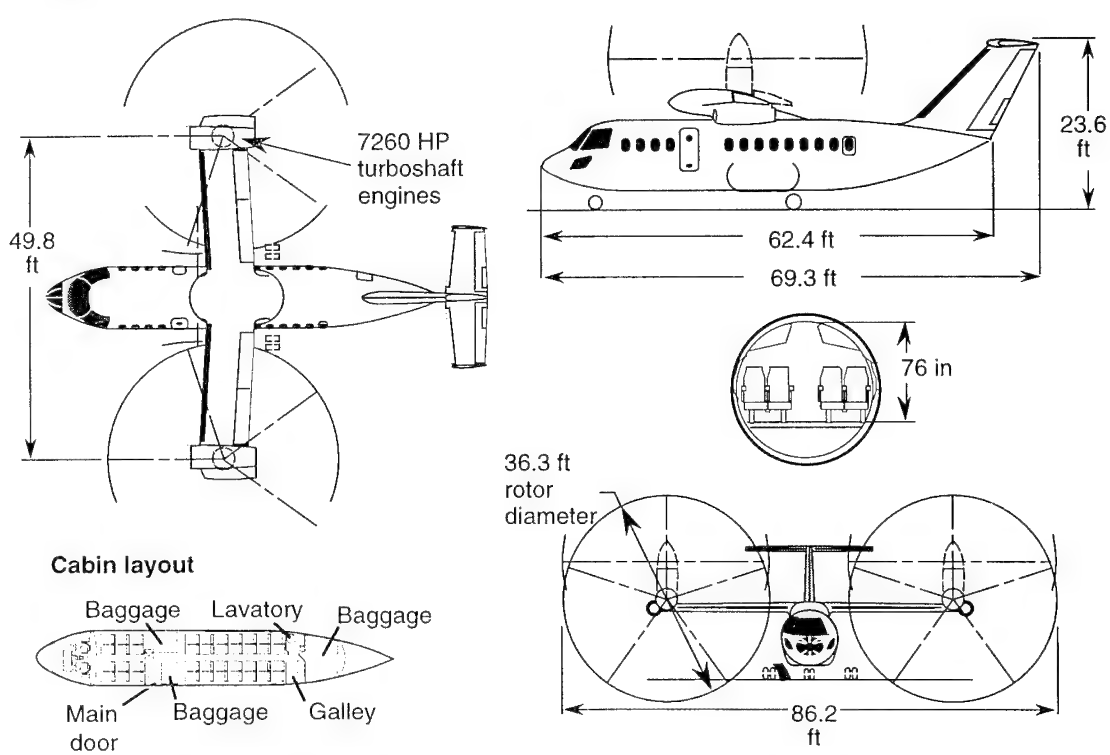
From regional airports to urban/suburban demand center vertiports.

- *Transfer Service*

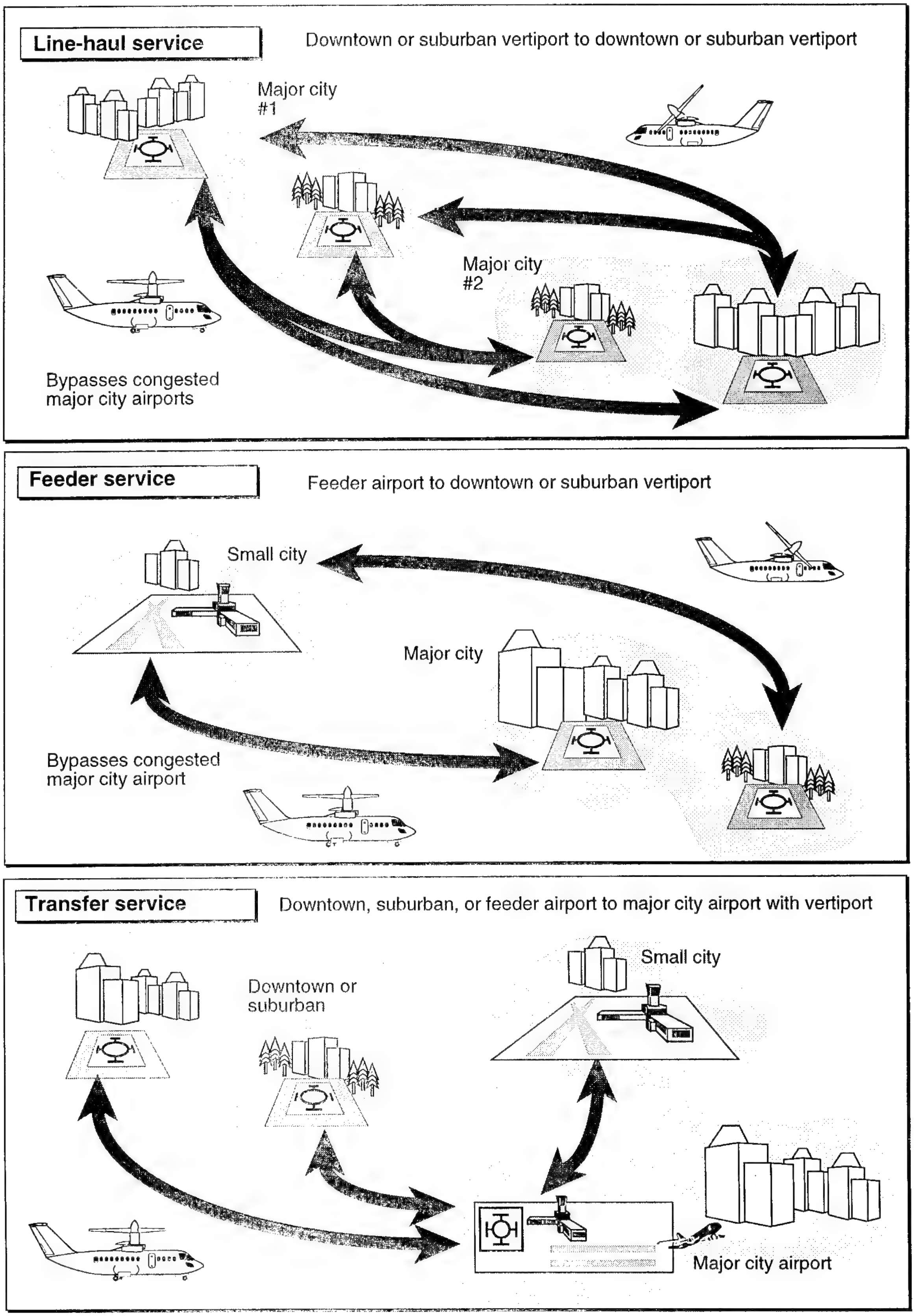
From a demand center vertiport to a vertiport located at a congested hub airport.

In addition to providing time and convenience benefits to passengers, a CTR system could also yield broader societal benefits by relieving congestion at major airports as a portion of current short-haul passenger traffic is diverted to vertiports. The development of CTR could also contribute to the vitality of the U.S. aircraft manufacturing industry.

CTR design concepts for a first-generation CTR build on the success of the XV-15 and V-22



A 40-passenger CTR would be suited to three primary commercial markets



CTRDAC Findings

The CTRDAC concluded that it is technically feasible to develop CTR aircraft and related infrastructure that could serve as an important component of the national transportation system. Developing a CTR system could increase transportation options for many travellers and offer an opportunity to reduce delays and congestion in the most heavily traveled U.S. corridors.

A CTR system could be economically viable, although there are substantial risks and uncertainties that must be overcome. CTRs would have safety performance comparable to current conventional jet aircraft. They would need to have emission levels and energy consumption levels comparable to turboprop aircraft.

CTR fares would be higher than conventional airfares, but the time savings and convenience would cause a significant number of passengers to divert to CTR. These trip time benefits will be achieved only if vertiports are located close to passenger demand centers. Because it is important to locate vertiports close to demand centers, it will be important to reduce aircraft noise to the lowest practical level and to site vertiports to minimize the adverse noise impact.

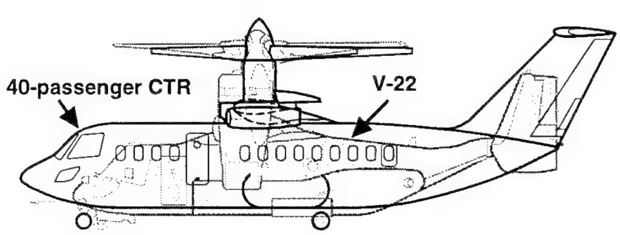
1. CTR is technically feasible and can be developed by U.S. industry.

- The combined knowledge gained from the XV-3, XV-15, and V-22 flight programs and the ongoing NASA Short-Haul Civil Tiltrotor program provides a sound foundation for the development of safe and environmentally acceptable CTRs for commercial passenger service.
- Additional research and development is needed before industry can make a production commitment for a large commercial passenger CTR.
- A small tiltrotor could be developed for the corporate and utility market using existing tiltrotor technology.

The committee found that a CTR is technically feasible and that a safe aircraft can be developed and certificated. With additional development, these aircraft have the potential to satisfy environmental concerns and be acceptable to passengers.

Additional research is needed because the present design of the V-22 military aircraft needs to be refined further in order to support the development of a practical civil vehicle. Research is needed in the areas of noise reduction, contingency power, aircraft flight controls, failure modes, composite materials, and vibratory loads.

The V-22 was designed for combat and shipboard environment while the 40-passenger CTR will be designed for comfort and profitable operation



The V-22 is designed for military missions and incorporates items not appropriate for civil missions:

- Folding rotor blades/wing and high-strength landing gear adds unnecessary weight and complexity
- Rotor system not optimized for low noise
- Military cockpit not optimized for steep-angle descents
- Cabin not pressurized for civil application

The larger CTR requires commercial technologies:

- Noise reduction - Optimized flight deck - Ultra-reliable/safe - Affordable acquisition

2. Successful CTR introduction depends on overcoming significant uncertainties and risks.

- **Decisions to manufacture CTRs, develop air and ground infrastructure, and provide scheduled passenger services are interdependent. They are also sensitive to potential demand, commercial viability, infrastructure financing mechanisms, and community acceptance.**

CTR service has the potential to compete profitably in a number of domestic travel corridors by reducing overall travel time, although fares would need to be higher than existing airfares. Manufacturers, however, will not launch a production program until they see a worldwide demand for CTR aircraft sufficient for program profitability as well as launch orders from a sufficient number of operators. They will also need to be confident that the necessary infrastructure is planned or in place and that there is a likely prospect for the evolution of a mature CTR system.

Similarly, operators will not order such aircraft until there are plans and commitments to provide the infrastructure and unless such aircraft offer the promise of profitable operations. Finally, local communities will not commit to the construction of vertiports without assurances that CTR aircraft will be produced and operated. This interdependency poses a challenge to the decision process for each party.

The analysis of the economic potential of CTR is sensitive to many assumptions, some of which are uncertain. In particular, it is always difficult to look 10 to 30 years into the future and precisely predict passenger demand in specific corridors, airline fares, or the state of airline competition. Other parameters such as aircraft capital and operating costs, vertiport site availability, and the competitive response of existing airlines are also difficult to predict. However, conservative assumptions were made to provide credible projections. The accuracy of ridership projections is further constrained by the limitations of available demand models and data.

These and other risks are both cumulative and interrelated. (See discussion of ridership and sensitivity under Finding number 4). Any one of these risks could impact CTR economic viability and all must be resolved for the successful development of a viable CTR system. The potential benefits of implementing this technology warrants additional work to address these risks and uncertainties.

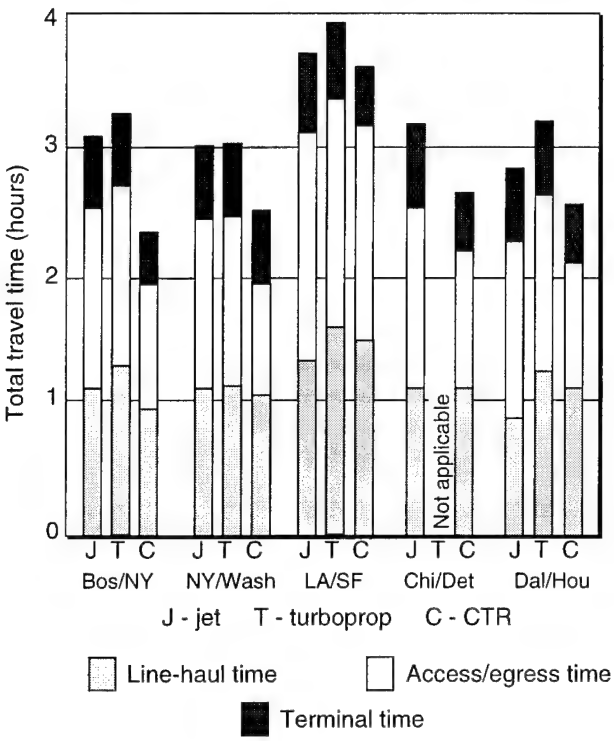
3. Vertiport siting is a critical factor in CTR system viability.

- **Planning for CTR infrastructure development should be integrated into national and local transportation system planning.**
- **Vertiport design criteria and CTR-compatible air traffic control (ATC) procedures need to be developed.**

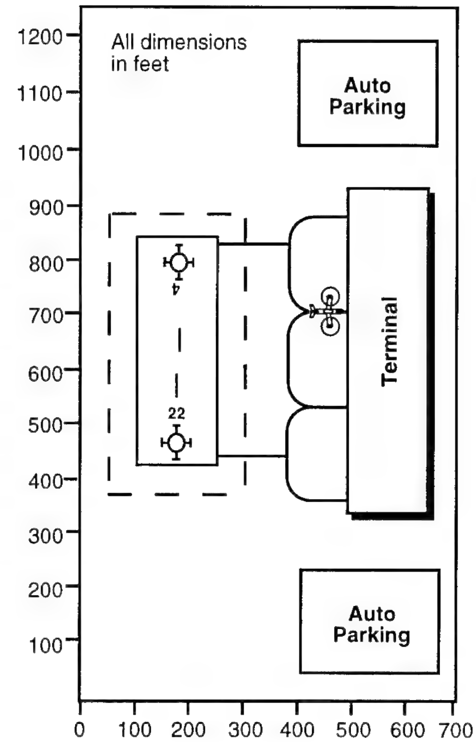
The CTRDAC concluded that close coordination and cooperation between public and private interests are essential for developing CTR ground and air infrastructure. An important factor that will ultimately determine the success of CTR aircraft is community acceptance of vertiports. Vertiport siting and financing are issues that require close cooperation between Federal, state and local planning authorities and vertiport operators. The Federal Aviation Administration (FAA) can develop a suitable airspace infrastructure to accommodate CTR aircraft within the planned ATC system while taking advantage of the inherent capabilities of CTR. However, no one party controls all the resources or regulations required to develop the necessary infrastructure.

Vertiports must be considered an integral element in metropolitan and local intermodal transportation facility and urban and community development plans. The actual construction of a system of vertiports would not proceed until a decision is made to manufacture a CTR aircraft.

Locating vertiports close to passenger demand centers is essential for taking full advantage of CTR capabilities and reducing travel time

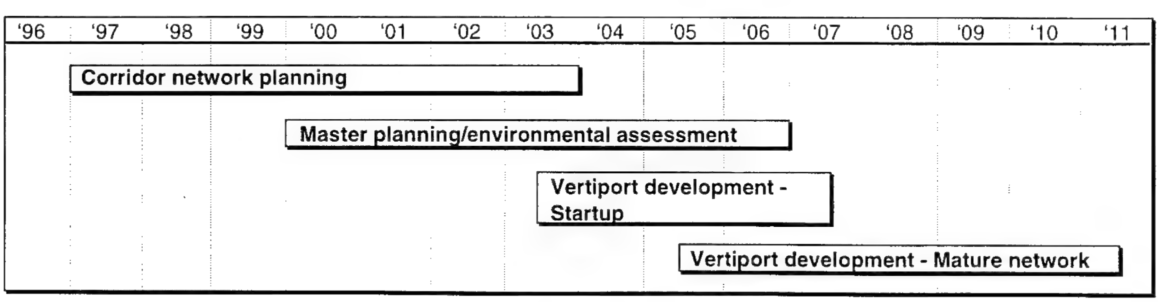


Although CTR vertiports require more land than a heliport, they require far less land than conventional airports



The minimum size of a vertiport in a suburban area or city center is between 10 and 30 acres. Smaller vertiport sizes are associated with multi-level facilities that might be designed for multiple uses and might incorporate multimodal connections. Current FAA community noise standards indicate that the area adversely impacted by noise would be 12 acres in an industrial area, 44 acres in a commercial area, and 119 acres in a residential area. In comparison, conventional urban airports, such as LaGuardia and Boston Logan, adversely impact 16,500 and 13,000 acres respectively. The size of the CTR noise-impacted area assumes only partial success of the NASA noise reduction program. If all NASA program goals were to be achieved, the area of land impacted by CTR noise would be reduced by approximately half.

Comprehensive planning and development of CTR infrastructure is needed to encourage operators to acquire CTRs and manufacturers to launch a production program



4. Under certain assumptions, a CTR system could be economically viable and operate profitably without government subsidy.

- CTR would attract a significant number of travelers willing to pay higher airfares for reduced overall trip time and greater convenience.
- CTRs could operate profitably without government subsidies in highly traveled corridors and produce an acceptable return on investment for manufacturers, CTR operators, and vertiport providers.
- CTR operators would compete more successfully in high airfare markets.

The analysis of CTR economic viability includes a Government/industry cost-shared research, development, and demonstration program costing approximately $600 million. This program would enable the launch of a commercial 40-passenger CTR manufacturing program in 2003 with first deliveries in 2007. The manufacturer development cost is estimated to be approximately $1.2 billion.

Four corridors were examined by the Committee: the Northeast from Boston to Washington, D.C.; the Midwest, including Chicago and surrounding cities; West Coast, including Los Angeles, San Francisco, and Las Vegas; and Southwest, including Dallas and Houston.

All net present values (NPV) in this analysis were calculated as of 1995. Discount rates of 10 percent for operators and 12 percent for manufacturers were used to reflect risk premiums, while a 7 percent standard Government discount rate was used to assess societal benefits and costs.

CTR Passenger Demand—It is estimated that CTR service could attract as many as 11 million passengers annually by the year 2010 for direct and feeder service in the four U.S. corridors. Additional demand is expected from air transfer passengers. The highest rate of diversion would occur in markets with high conventional airfares such as the Northeast and some Midwest city pairs.

The potential market for CTR service by the year 2010 depends on factors that include airport congestion, existing fare structures, and competition from conventional airlines

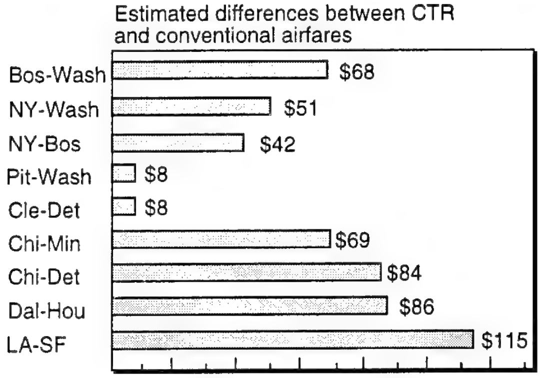
Corridor	Percent Diverted From Air	Typical Fare Premium (percent)	Number of CTR Enplanements
Northeast	20	45	5.9 million
Midwest	12	15 to 125	3.5 million
West Coast	4	135	1.5 million
Southwest	6	130	0.3 million
Overall	**11**		**11.2 million**

CTR ridership estimates are sensitive to various assumptions. The most important assumptions involve airfares and travel times for both CTR and conventional aircraft and vertiport siting. CTR demand is very sensitive to the level of assumed CTR fares. Reductions in CTR fares would lead to significant increases in CTR ridership, while increases in CTR fares would lead to relatively smaller decreases in CTR demand estimates. Ridership estimates are not as sensitive to changes in either CTR or conventional air travel times as they are to changes in fares. However, reductions in CTR line haul travel times would likely produce twice the impact on ridership as increases in CTR travel times.

CTRDAC analyses considered the sensitivity of CTR ridership to a number of variables

Variable	Change in Assumptions	Change in CTR Ridership
Conventional airfares	+15%	+17%
	-15%	-17%
Conventional air delay per operation	+20%	+9%
CTR fares	-10%	+45% to +80%
	-20%	+95% to +160%
	+20%	-45% to -70%
CTR initial price	+10%	-10%
	-10%	+10%
CTR line-haul travel time	+10%	-7%
	-10%	+14%
Vertiport locations	All less favorable	-31% to -33%

The baseline fare premiums projected for CTR travel can be measured against the potential reduction in travel time and convenience



Vertiport location is also an important determinant of CTR ridership. If all vertiports were located in less favorable locations, outside of major demand centers, CTR ridership would likely drop by as much as one third.

Forecasts indicate that congestion at conventional airports will continue to grow and that airline ticket prices at congested hubs are consistently higher than ticket prices at uncongested hubs. With local communities concerned over noise impacts and local traffic, siting vertiports may pose a challenge. However, good vertiport sites may be available because many major cities are located on waterways, serve as rail centers, or have large industrial areas in close proximity to central business districts. Suburban locations often have existing general aviation airports that may be available for CTR operations.

Manufacturer Viability—It is estimated that between 235 and 325 CTR aircraft will be needed in the four corridors in the year 2010. The worldwide demand is estimated to be between 1160 and 1600 aircraft.

The entire manufacturing program, including a 2003 program launch and manufacturing from 2007 to 2027, would produce an NPV of $273 million discounted at 12 percent. The manufacturer would require sales of approximately 500 aircraft over the first 10 years to break even.

The projected demand for CTR aircraft in the U.S. in the year 2010 is only part of a potential worldwide market

Market Region	Forecast Range
Four major U.S. corridor markets (note 1)	235 to 325
Other North American corridor markets (note 1)	150 to 200
Europe	300 to 400
Japan	300 to 400
Oceania	100 to 125
Total passenger CTRs	1,085 to 1,450
Other applications (note 2)	75 to 150
Total	**1,160 to 1,600**

Note 1: Vertiport-to-vertiport, plus feeder, plus transfer markets. Transfer market included in top end of the range

Note 2: Other worldwide applications for 40-seat aircraft include package express, corporate, search and rescue.

Operator Viability—The return to CTR operators is based on the relationship between fares charged and CTR capital and operating costs. Using base case fare premiums, operators could earn a real rate of return of 11 percent over the 2007 to 2027 time frame. The operator cash flow has an NPV of $26.5 million in 1995 when discounted at 10 percent.

Near-term airline interest in the CTR is expected to be limited because their planning horizon is considerably shorter than the projected CTR launch date. Airlines are currently concentrating on restoring profitability after several years of unprecedented losses. In addition, priority is being given to replacing and upgrading conventional aircraft fleets. Since deregulation, competition has led the airlines to make decisions in ways that minimize risks. CTR still faces significant risks and uncertainties. Until these are resolved, airlines can be expected to adopt a wait-and-see attitude.

Infrastructure Viability—CTR infrastructure could be developed and operated on a self-sustaining basis. This conclusion is based on an analysis

of vertiport land acquisition, design, construction, and operating costs in relation to likely landing fee levels, concession revenues, passenger facility charges (PFC), and/or Airport Improvement Program (AIP) funds. A phased planning and construction program for vertiports is anticipated with a total capital expenditure of approximately $670 million over 11 years. Initial CTR operations would make use of expanded existing heliports and airports. New vertiports would be brought on-line as demand for CTR service matures. The analysis found that approximately 27 vertiports in 16 cities would meet projected levels of demand in 2020 in the four U.S. corridors. Fourteen of these vertiports would be at existing general aviation and commercial airports while 13 vertiports at new locations would be required. Siting vertiports at appropriately located general aviation airports or at uncongested commercial service airports simplifies infrastructure planning considerably and reduces overall costs.

5. CTR could produce significant societal benefits.

- Using CTRs could reduce congestion and resulting delays at existing airports.
- CTRs could reduce total investment required for other transportation infrastructure.
- A U.S.-developed CTR would create jobs and could have a positive impact on the balance of trade.

The primary societal benefit resulting from the introduction of scheduled CTR service will be the reduction in congestion and delays at conventional airports as some passengers move from conventional aircraft to CTRs.

It is estimated that the total benefit of delay reduction to passengers and airlines would range from approximately $400 million to $1.4 billion per year, depending on the level of congestion and delays assumed to exist in the year 2010 and the overall market penetration of the CTR in the four U.S. corridors. The discounted cash flow analysis of overall societal benefits is based on the lower end of the range of annual delay reduction benefits. When discounted at 7 percent per year, the NPV of delay reduction benefits in 1995 is estimated to be $1.2 billion.

The economic analysis assumed that private investors will require a risk premium to invest in CTR production and operations. As such, their cash flows were discounted at 12 percent for manufacturers and 10 percent for operators. This is higher than the 7 percent rate used in estimating the overall societal benefits for CTR and accounts for the differences in manufacturer and operator NPVs shown in the table. The overall NPV to society in 1995 of CTR research, development, production, and operation over a 20-year period is approximately $1.9 billion. The choice that Government faces is whether it is appropriate to share with industry the $435 million (NPV) in research and development needed to achieve a potential delay reduction benefit of $1.2 billion.

The total overall NPV in 1995 of all benefits and costs of implementing a CTR system is estimated to be $1.9 billion, based on estimates of CTR market penetration and delay reduction

Category	Government-Private NPV (millions of $)	Societal NPV (millions of $)
Government/industry research and development	$(435)	$(435)
Industry vehicle production (discounted at 12 percent for private NPV and 7 percent for societal NPV)	$273	$900
Vehicle operations (discounted at 10 percent for private NPV and 7 percent for societal NPV)	$27	$175
Delay reduction	$1,230	$1,230
Infrastructure	0 *	0 *
Total	**N/A**	**$1,860**

* Self-financed from CTR operator fees and passenger ticket taxes and/or user fees.

There are other societal benefits from the introduction of the CTR, including reduction in total travel time, job creation, positive effects on the balance of trade, and continuing technology leadership.

There is also the possibility of CTR technology enhancements impacting other rotocraft and conventional aircraft development and manufacturing. Offsetting some of these benefits could be small projected increases in energy consumption and emissions.

CTRDAC Recommendations

CTR technology has the potential to offer considerable societal benefits by advancing transportation in the U.S. Therefore, the CTRDAC recommends expanding the ongoing Government/industry cooperation in CTR research and development and related matters necessary for eventual introduction of commercial operations. The tiltrotor concept holds sufficient promise to warrant additional investment of funds and effort.

1. Create a public/private partnership to address CTR institutional, infrastructure, and coordination issues.

- The Federal Government should take the lead in coordinating activities and facilitating necessary interdependent decisions. It would lead a public/private partnership established to create an overall plan covering all critical elements needed to conduct research and establish a CTR short-haul transportation system. The partnership would provide specific criteria for periodic evaluations to continue, redirect, or terminate the plan.
- Conduct a detailed network study of a promising corridor to clarify vertiport siting issues.

The recommendation made for continuing Government/industry cooperation are consistent with a long, successful history of Government involvement in civil aeronautics technology. A public/private partnership is a necessity for the successful introduction of CTR service. Many of the most important issues require simultaneous decisions in both the pubic and private sectors. The Federal Government should take a strong lead in developing necessary information, coordinating CTR activities, and facilitating the necessary decision and planning process. In view of the critical nature of issues relating to vertiport location, community acceptance, and the long-lead time needed to plan and develop infrastructure, state and local governments will need to begin participating in site identification and preliminary vertiport planning.

The CTRDAC recommends that the vertiport and ATC planning process begin immediately and that a detailed vertiport network plan be developed for the most promising corridor. This can be accomplished with limited funds for planning and design prior to a full manufacturing commitment to build an aircraft. Funds required for actual vertiport construction and ATC services would not be committed until after an aircraft launch decision is made by manufacturers.

2. Proceed with an integrated CTR aircraft and infrastructure research, development, test, and demonstration program.

- Reduce technical and community acceptance risks in a phased program that can be accelerated or terminated at set points as results warrant.
- The approximately $600 million cost over 10 years would be shared by Government and industry.

The CTRDAC recommends a phased tiltrotor research, development, and demonstration program that would cost approximately $600 million with the total cost being shared by Government and industry. The Committee also proposes that the level of industry cost sharing increase as CTR technology moves closer to market introduction. Required advances in technology are achievable and should be demonstrated to the public and

potential CTR operators. The test and demonstrator phase is important to gain confidence in key research elements, to finalize air and ground infrastructure design standards, and to demonstrate to local communities flight procedures that are optimized to reduce environmental impact and provide for passenger comfort. This will allow an informed decision by all parties concerned by the year 2003.

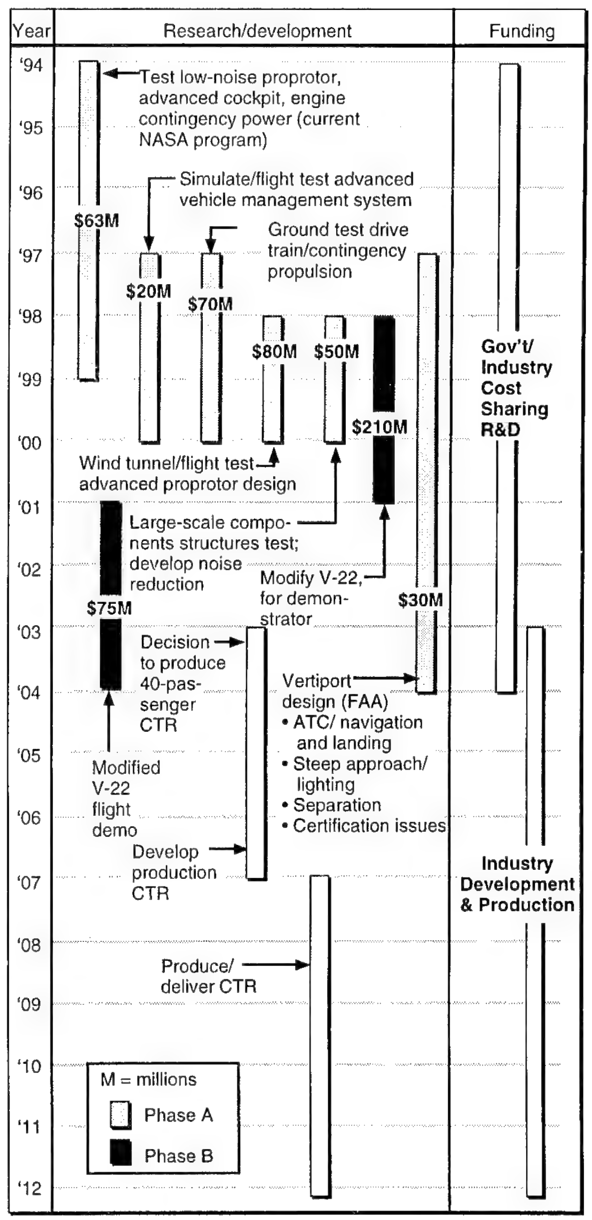
The committee recommends a phased approach to the required research and development that could be terminated after each phase if the results do not show a promise for CTR community acceptance and economic viability. The committee recommends a coordinated research and development program to reduce technical risks in CTR safety and environmental areas. This program, led by NASA with FAA and industry participation, should include:

- Aircraft design to reduce external noise.
- Flight profiles that result in low noise level operations while ensuring safety.
- Performance capabilities when one engine is inoperable.
- Flight deck design and flight characteristics that recognize the human factors contribution to safety and minimize differences from other aircraft.
- CTR systems condition and usage monitoring systems.
- Advanced drive train.
- Composite structures.
- Internal noise/vibration reduction.
- Flight demonstrator to test key research components and to assess community response.

The committee recommends that the FAA lead a coordinated research and development program of infrastructure and regulatory research in the following areas:

- Development of advanced navigational technologies such as Global Positioning System (GPS) for approach and departure and as an element for automatic dependent surveillance (ADS) for CTR aircraft.
- Vertiport design.
- Air traffic control and airspace design to accommodate CTR.
- Development of CTR terminal instrument procedures.

A comprehensive, integrated Government/industry research and development program totalling approximately $600 million could lead to a CTR launch decision in 2003



3. Continue and accelerate work on regulatory and certification issues.

- Develop a plan for changes to the ATC system in potential CTR corridors.
- Begin safety and environmental standards development related to CTR regulatory requirements.

The committee recommends that the FAA continue and expand current efforts toward achieving necessary ground and airspace infrastructures to accommodate a CTR system. Topics of particular relevance include (1) advanced navigational technologies such as GPS for CTR navigation and approach and departure guidance and as an element of ADS of CTR aircraft, (2) revision of Advisory Circulars related to vertiport design and airport land-use compatibility planning, as well as criteria for establishing vertiport ATC towers, (3) design and implementation of airspace in the vicinity of vertiports, and (4) modification of the Code of Federal Regulations, 14CFR77, Objects Affecting Navigable Airspace. Similarly, existing draft CTR certification standards and procedures must be finalized during the certification process.

4. The Department of Transportation should initiate a multimodal study of options, including CTR, to increase intercity transportation capacity.

- The CTR should be included in analyses of transportation improvements in specific heavily traveled corridors.
- All options, including CTR, should be examined to determine which solution or combination of solutions are most appropriate in economic, environmental, safety, and other dimensions.

There are various options available to help meet the growing demand for short-haul transportation in intercity corridors. The Department of Transportation is charged with assessing national intercity transportation system requirements and should include the CTR among the options considered to meet national transportation needs. The Department of Transportation is presently undertaking a Congressional study of the commercial feasibility of high-speed rail. It would be preferable to address these issues on a multimodal basis.

Other options might include:

- Building new airports or expanding existing aviation facilities.
- Improving ATC system capacity.
- Developing new higher speed rail systems.
- Using demand management to reduce existing congestion.

One or more of these alternatives, including the CTR, will likely be required to satisfy the growing demand for intercity passenger travel. It is important to find the most cost-effective and environmentally compatible solutions for each transportation corridor. These may not be the same for every U.S. transportation corridor.

1.0 Introduction

1.1 Legislative Basis

Section 135 of the Airport and Airway Safety, Capacity, Noise Improvement, and Intermodal Transportation Act of 1992 directed the Secretary of Transportation to establish a Civil Tiltrotor Development Advisory Committee (CTRDAC). The broad mandate of the CTRDAC is to determine:

- The costs, feasibility, and economic viability of development of tiltrotor aircraft and their integration into the national transportation system.
- The benefits of tiltrotor development to our national economy and transportation system.
- Further research and development (R&D) required to incorporate civil tiltrotor (CTR) aircraft into the national transportation system.
- Necessary changes to regulatory standards governing use of the airspace system needed for the introduction of CTR aircraft.
- The allocation of aircraft and infrastructure development costs between the Government and private sector.

This report contains and transmits to Congress CTRDAC findings and recommendations.

1.2 CTRDAC Approach

If CTR transportation services are to become a reality, coordinated decisions and major financial commitments are required from numerous independent public and private sector entities, including manufacturers; state and local governments; vertiport developers and operators; new or existing air carriers; regulators; and the aeronautics research community. The key to assessment of the ultimate viability and implications of CTR development, and to identification of recommended near-term R&D and other Federal actions, lies in careful examination of the factors that will drive long-range governmental and corporate investment and other decisions in technologies and related infrastructure.

The CTRDAC addressed its objectives by forming subcommittees in the primary technical areas bearing on these decisions: (1) Aircraft, (2) Infrastructure (air and ground), (3) Environment and Safety, and (4) Economics.

Each subcommittee examined ongoing and past studies, assessed current knowledge from available sources, and determined CTR status and requirements in its technical area to the extent practicable at this stage in the evolution of the CTR. The Economics Subcommittee reviewed and provided direction to FAA-sponsored analyses of CTR ridership, costs, economic viability, societal benefits, and investment attractiveness. Where appropriate, this analysis makes use of demand forecasting models used recently for other transportation modes, such as high-speed rail and magnetic levitation systems.

The CTRDAC integrated the results obtained by the four subcommittees into an summary response to the questions raised in the enabling legislation. Significant financial and technical unknowns remain in each area, leading the Committee to identify future research needed to reduce the uncertainty and risk associated with each of the critical issues indicated above. The Committee also found it appropriate to develop recommendations concerning the necessity for cooperation and coordination among the various participants who would logically be involved in the introduction of commercial CTR service.

This report presents the key topics considered in the work of the subcommittees. Individual subcommittee reports are included in Volume II of this report.

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2.0 Background

2.1 The Civil Tiltrotor-A New Option for Intercity Passenger Travel

During the last four decades, the U.S. Government has made a large investment in research and development directed toward aircraft capable of vertical take-off and landing with conversion to fixed-wing flight en route between origin and destination. The combination of these capabilities in one aircraft holds the potential for speed, operating cost, and range advantages over helicopters while requiring considerably less airport land than conventional passenger aircraft. Based on extensive research, the tiltrotor concept is now the dominant technology for this application. Most of this ongoing development has focused on military applications and has been funded by the Department of Defense (DoD) with substantial research and development support from the National Aeronautics and Space Administration (NASA).

In recent years, there has been growing interest in a civil tiltrotor (CTR) aircraft to serve short-haul (100 to 600 mile) air passenger markets. It is anticipated that the CTR would relieve congestion at airports serving major cities as well as improve overall air service for the traveling public. CTRs can operate at conventional airports independent of congested runways. In addition, CTRs will operate at small landing areas, called vertiports, that are designed specifically to accommodate the needs and capabilities of this unique aircraft.

The CTR resembles a twin-engine turboprop aircraft with large proprotors mounted at the wingtips. For takeoff and landing, the proprotors are rotated to a horizontal plane, giving the appearance of a tandem helicopter. When airborne, the proprotors are returned to a vertical plane, yielding flight characteristics similar to a conventional turboprop airplane, providing for high-speed cruise flight with low external noise levels.

A research aircraft using this concept first flew in 1955. This XV-3 aircraft was followed by the flight of the XV-15 in 1977. Although the CTR design is technically complex, the initial success of the XV-3 and XV-15 and the potential value of the CTR concept stimulated further development. In the 1980s, the U.S. Marine Corps V-22 Osprey was designed and prototypes were manufactured. Technical advances in lightweight structures, digital flight controls, and turboshaft engines have made the tiltrotor a practical concept.

The significant ongoing DoD and NASA research and development effort has created the potential for a new intercity passenger transportation service that could yield benefits to travelers and the entire U.S. aviation system. It could also contribute significantly to the vitality of the American aircraft manufacturing industry.

As a result of ongoing DoD programs, prototype tiltrotor aircraft that could provide the engineering foundation needed for a 40-passenger CTR are being tested and evaluated, with production planned. These units, combined with future CTR research, provide a foundation for assessing the prospects for the development and commercial operation of CTR-based transportation services in the early years of the 21st century. A 40-seat CTR is considered best suited to three primary commercial markets (figure 2.1-1):

- *Line-Haul Service*

CTRs would operate from vertiport to vertiport between urban/suburban area centers with high passenger demand. These markets have strong flows of business travel. Ground access to major conventional airports is already difficult, particularly at peak hours.

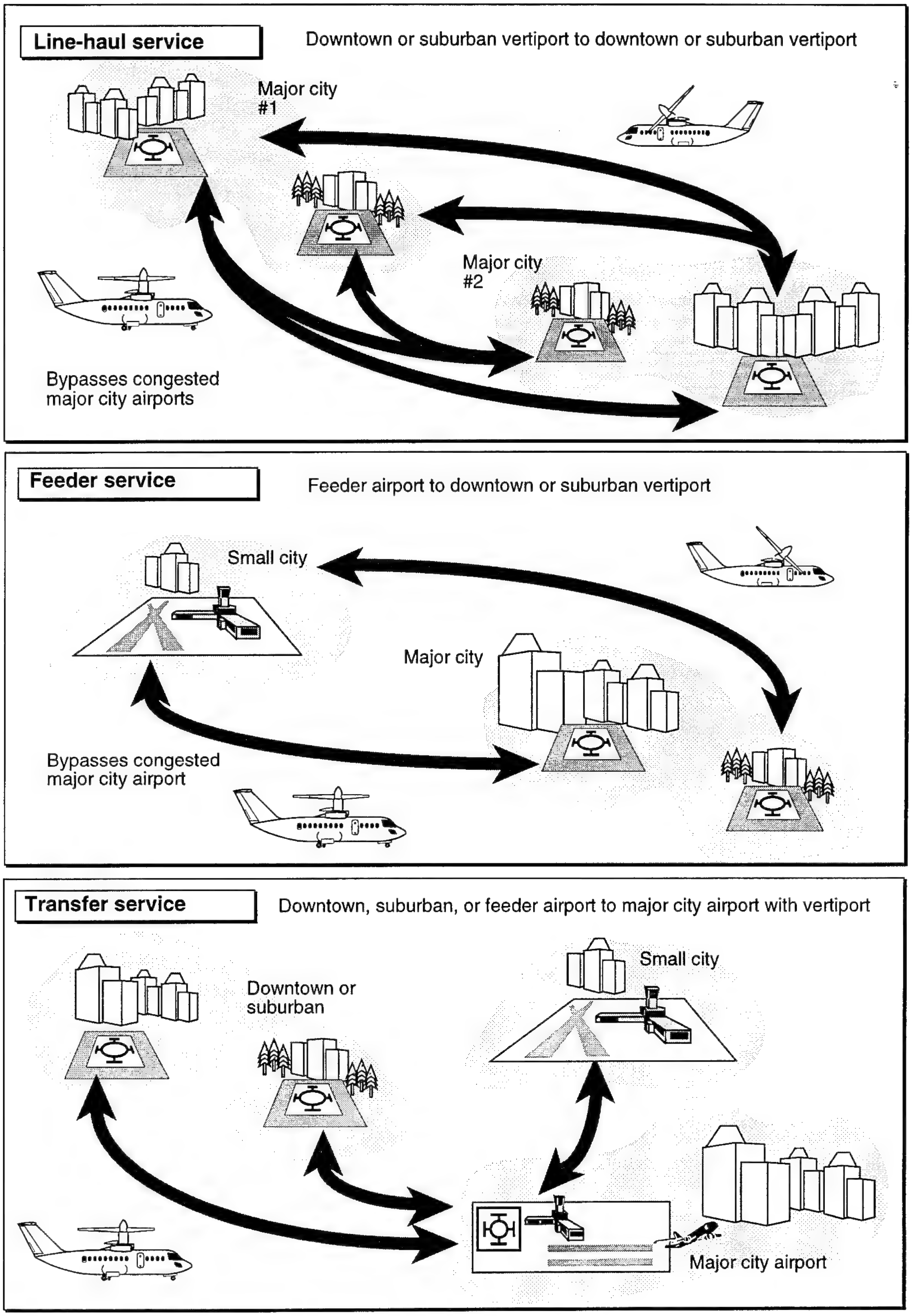


Figure 2.1-1 Potential CTR Commercial Markets

- *Feeder Service*

CTRs would operate from conventional regional airports to urban/suburban area demand center vertiports. This service would connect airports in small cities with metropolitan stand-alone vertiports, improving traveler convenience.

- *Transfer Service*

CTRs would operate from a demand-center vertiport or airport in a small city to a vertiport collocated at a congested conventional hub airport.

As currently envisioned, a CTR-based system would allow business and other travelers to depart from a conveniently located suburban or downtown terminal and arrive at a city center destination, significantly reducing total travel time compared to alternatives. Since CTR transportation is expected to carry a somewhat higher cost, even with reduced terminal access expenses, this time savings and convenience are key to the potential commercial attractiveness of CTR service.

Because of its excellent low-speed handling characteristics, a CTR aircraft can approach the vertiport at much lower speeds and much higher approach angles than jet or turboprop airliners. Initial normal CTR operations would involve an approach glidepath of approximately 9 degrees with the potential to increase the glidepath to 12 or 15 degrees. The steeper angle is important because the CTR will remain at a higher altitude during the approach than a fixed-wing aircraft. This will reduce its noise impact. At 9 degrees, the CTR aircraft would be approximately 800 feet above the ground at 1 mile from the landing point. By comparison, a conventional aircraft at the current 3-degree glidepath would be 270 feet above the ground at a similar distance from the landing point. The land area needed for operating a CTR at a typical vertiport would be much less than land needed for a typical airport. For these reasons, urban, waterfront, industrial, or business locations appear particularly suited for city-center CTR operations.

Besides the 40-passenger, short-haul civil transport mission, there are other potential CTR missions, including package express and mail, offshore oil production, corporate transport, and emergency medical service (EMS) transport. Although other size transports are possible, carrying from 9 to 75 passengers, the 40-passenger configuration is considered to have the largest initial market potential and to provide the greatest benefit to the traveling public and the greatest overall level of societal benefits. For these reasons, the 40-passenger aircraft was used for the analysis performed by the committee.

2.2 Future Intercity Passenger Transportation Environment

The outlook for short-haul, intercity passenger transportation in the United States varies widely by location and mode with large differences among regions in terms of growth and ability to absorb anticipated increases. Overall, travel via most modes, including air, continues to grow more rapidly than population at a typical rate of 2 percent to 3 percent per year. In the aviation sector, congestion and resulting delays at major airports, are a widespread cause for concern. These delays are projected to continue to increase in spite of air traffic control improvements, greater use of larger aircraft, and runway improvement projects.

The short-haul portion of the air market is very significant at some airports. At Logan Airport in Boston, for example, 44 percent of the scheduled departures and arrivals in April, 1995, were performed by aircraft with 50 or fewer seats flying 500 or fewer miles. At eight out of ten other major U.S. airports, the comparable figure was 23 percent or greater. Diversion of these short-haul flights to CTR could reduce congestion on the roads and in airspace associated with these airports and could reduce pressures for expansion, as well as providing more satisfactory service for CTR passengers.

Although recent years have seen much interest and activity in support of very high-speed rail and magnetic levitation (MAGLEV) systems, these

alternatives do not appear likely to be implemented for short-haul transportation in the next decade. The large infrastructure costs and right-of-way issues associated with very high-speed (above 150 miles per hour) ground systems, including major research and development (R&D) investment in the case of maglev, are major obstacles to their deployment. The current emphasis on an incremental approach to high-speed rail suggests that there will be ample opportunity for CTR to attract time-sensitive travelers. The modest upgrade of the rail service between Boston and New York City could help address airport congestion in that area. However, this would not preclude a market for CTR.

2.3 Current CTR Status

2.3.1 Aircraft

Although no CTR prototype aircraft exists, a military tiltrotor aircraft roughly the size envisioned for a civil mission does exit. This military aircraft, the V-22 Osprey, is an assault transport that is now being flight tested and is scheduled for production with deliveries beginning in 1999. Based on the current delivery schedule, the V-22 will have 60,000 flight hours by the year 2005. There is a general consensus that the unique military capabilities built into the V-22 make it an unlikely candidate for a CTR even in a modified form. However, as the military gains experience flying the V-22 over thousands of flight hours, this will add to the general knowledge of tiltrotors and will be helpful to designers of the CTR.

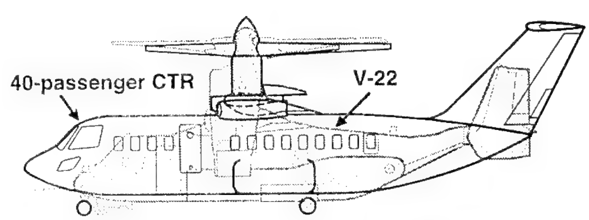
Although a CTR must have a substantially different design from the V-22, there would be enough similarities in certain critical components that extensive V-22 operational experience would provide some helpful information to civil designers in terms of failure modes. While the V-22 and the CTR would be used for different missions, the basic aeromechanics and flight characteristics are common and would benefit CTR design activity.

The major U.S. helicopter manufacturers are currently cooperating with NASA through the Short-Haul Civil Tiltrotor R&D effort. This program, budgeted at approximately $8 million per year, addresses technologies critical to the eventual production of a successful CTR, including noise reduction, contingency power, and the integration of system elements.

A tiltrotor configuration has never been certificated by Federal Aviation Administration (FAA) for civil use. The V-22 technology and the advances embodied in the existing CTR conceptual designs suggest that there are no insurmountable obstacles to certification, but a substantial amount of research and flight testing will be necessary to reduce the risks of failure or delay in the initial CTR certification (figure 2.3.1-1).

2.3.2 CTR Regulatory Standards

The FAA has cooperated for over a decade with NASA and DoD on CTR-related issues. The FAA has focused primarily on exploring the feasibility of commercial tiltrotor operations and defining associated air traffic control and vertiport design requirements. FAA Interim Airworthiness Standards for Transport Category Powered-Lift Aircraft have been published and pilot and instructor



V-22 is designed for military missions and incorporates items not appropriate for civil missions:
- Folding rotor blades/wing and high-strength landing gear adds unnecessary weight and complexity
- Rotor system not optimized for low noise
- Military cockpit not optimized for steep-angle descents
- Cabin not pressurized for civil application

Designed for combat and shipboard environment

Larger CTR requires commercial technologies:
- Noise reduction
- Optimized flight deck
- Ultra-reliable/safe
- Affordable acquisition

Designed for comfort and profitable operations

Figure 2.3.1-1 V-22/CTR Comparison

certification rules have been proposed in the Federal Register. A vertiport design advisory circular (AC) has been published, and a cooperative effort with industry to revise this document is underway.

2.3.3 CTR Infrastructure Planning

A total of $3 million in grants was awarded to state and local governments for vertiport feasibility studies in the period 1989 to 1993 under the Airport Improvement Program (AIP). These studies were conceptual in nature. To date, no integrated studies of specific area networks have been accomplished. Many vertiport design and airspace management topics remain to be addressed in detail, including instrument approach angles, air traffic pattern procedures, aircraft separation standards, wake turbulence, and noise criteria.

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3.0 CTR Technology

- With additional research, a safe and efficient CTR aircraft can be built by U.S. manufacturers and certificated by the FAA.
- Current research by Government and industry is insufficient to produce adequate technology for introduction of a 40-passenger CTR. It is also insufficient to maintain the current lead of U.S. industry that would ensure U.S. participation in a worldwide CTR market.
- A new, $568 million, shared-cost Government/industry research and demonstration program is needed to develop the critical noise, cockpit, engine/drivetrain, and composite structures technology.
- Reducing external noise is the most important and most difficult research area.

The Civil Tiltrotor Development Advisory Committee (CTRDAC) used the CTR2000 civil tiltrotor conceptual design for all of the analysis contained in this report. The CTR2000 is a design concept for a 40-passenger, short-haul civil tiltrotor (CTR) aircraft with characteristics shown in figure 3.0-1.

The XV-3 tiltrotor research aircraft was flown in the 1950s and 1960s and the XV-15 tiltrotor is still being flown today. Flight tests and wind tunnel tests of these aircraft resulted in considerable knowledge of tiltrotor technology and led directly to the design of the V-22 Osprey, the current military tiltrotor aircraft now undergoing flight testing and is funded for production to begin in the late 1990s.

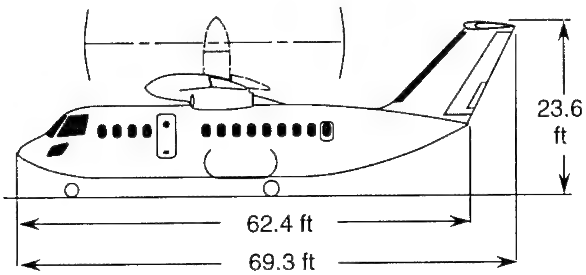
All CTR designs are fundamentally different from the V-22 that was designed for operations aboard Navy ships. This design constraint greatly affected the structural weight of the V-22, the size and type of proprotor, and the wing and tail design. There are many features of the V-22 that are not necessary for a CTR. For example, there is a pivoting mechanism where the wing meets the fuselage. The pivot allows the wing to fold backward, nearly parallel to the fuselage. This makes the vehicle more compact for parking on a ship hangar deck. Such military-specific features make the V-22, or even a highly modified V-22, unsuitable for the civil mission. For this reason, an entirely new CTR design will be necessary for the civil market. New technology must be developed to achieve a low-noise rotor, civil cockpit, and one-engine inoperable capability.

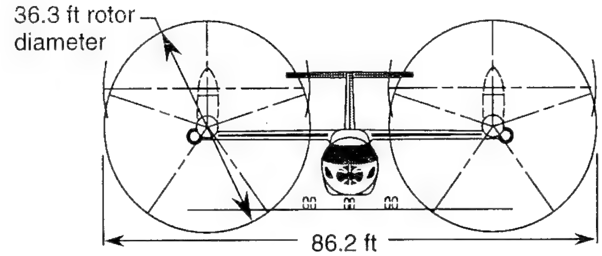
The CTRDAC reviewed information from the XV-3, XV-15 and V-22 tiltrotor programs and compared this with the CTR2000 design. The committee also solicited technical opinions and past experience from all major U.S. helicopter manufacturers (Bell, Boeing, Sikorsky, and McDonnell Douglas), the National Aeronautics and Space Administration (NASA), Department of Defense, and the Federal Aviation Administration (FAA).

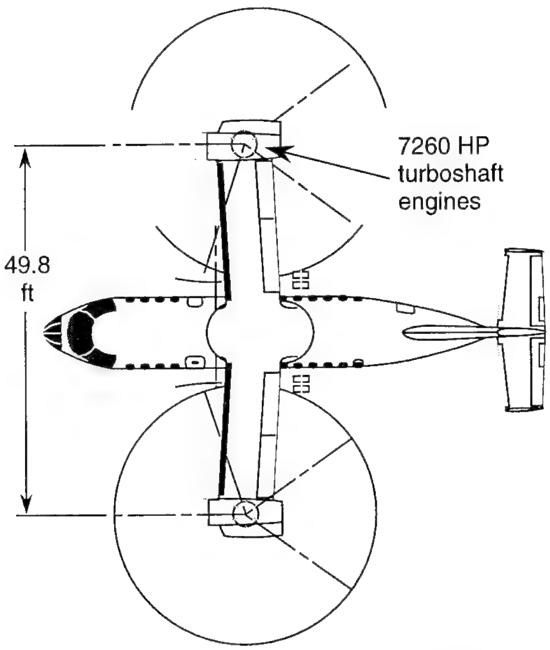
The committee analyzed the following aspects of the civil tiltrotor design:

- External noise reduction
- Contingency engine power
- Flight control systems
- Internal noise/vibration reduction
- Composite materials
- Manufacturing
- System condition and usage monitoring technology
- Autorotation
- Icing

Committee findings are discussed in the following paragraphs.







Rotor diameter	36.3 ft
Fuselage length	62.4 ft
Height to top of tail	23.6 ft
Number of blades per rotor	5
Width (rotor tip to rotor tip)	86.2 ft
Maximum vertical takeoff weight	43,150 lb (sea level, standard day)
Empty weight	28,623 lb
Cruising speed	315 knots (true airspeed at 30,000 ft)
Maximum continuous power speed	350 knots (true airspeed at 30,000 ft)
Passenger seats	40
Service ceiling	32,000 ft
Range	600 nm (full passengers and IFR fuel reserves)
Horsepower per engine (max static)	7,260 shaft horsepower at sea level, standard day

Figure 3.0-1 CTR2000 Characteristics

3.1 External Noise Reduction

CTR proprotor noise will be at its highest level on approach in the helicopter mode. The reduction of this external noise is a major requirement for community acceptance of CTR aircraft. Communities are likely to demand much quieter rotors on a CTR than the three-blade rotors used on the V-22.

A variety of techniques are being investigated to produce the optimum low-noise proprotor design, including increasing the number of blades (e.g., four or five on each proprotor), lowering the proprotor tip speed, and designing advanced blade tip shapes. Currently, this research, which includes wind tunnel and flight testing, is being conducted by NASA and industry.

While Federal noise certification and regulations are important, an effort should be made to understand the community noise pollution standards in place around the country that could affect the operation of CTR aircraft in local communities. The Code of Federal Regulations, 14CFR36, states that, "Compliance with Part 36 is not to be construed as a Federal determinant that the aircraft is acceptable from a noise standpoint in particular airport environments, -- responsibility for determining the permissible noise levels of aircraft using an airport remains with the proprietor of that airport and surrounding community." Any limitation placed on the operation of any aircraft at any public airport must comply with the provisions of 14CFR161 and may not be discriminatory nor impose undue burden on interstate or foreign commerce.

The established standard for federally funded airports provided by 14CFR150, which can be superseded by community requirements, estab-

lishes a day-night-level (DNL) metric that is both a time- and frequency-weighted metric. Three levels are prescribed: DNL 65 dB for residential environments; DNL 70 dB for business environments; and DNL 75 dB for industrial environments. Using this metric, one night time operation is weighted the same as ten daytime operations. While there is some question as to whether existing noise metrics properly account for the impact of low-frequency sound on human acceptability, the 14CFR150 requirements must be viewed as the best standard that currently exists. The subjective noise evaluations now being made may eventually lead to adjustments of these metrics. Based on the 14CFR150 requirements, the goal should be for CTR to achieve noise levels 10 to 12 dBA lower than the V-22.

The goal of the current NASA research and development program is to reduce the CTR noise level to 12 dBA below the V-22. Half of this reduction would be achieved by flight path management and half by reducing noise with an advanced proprotor design. Flight path management reduces noise by varying vehicle airspeed and descent rate to minimize sound levels on the ground while maintaining safety of flight for the aircraft.

3.2 Contingency Engine Power

FAA regulations require that following a single engine failure at any point in the mission, an aircraft must be able to fly away or hover and then land. This requires that the engine that has not failed must have substantial emergency power. Because safety is a preeminent requirement for any passenger-carrying operation, achieving one-engine-inoperative (OEI) capability anywhere in the flight envelope is essential.

One way to achieve this emergency power requirement is to design the vehicle with excess power. However, the weight, fuel consumption, and operating cost of the vehicle during its entire life suffers substantially from this ability to produce excess power. Another approach relies on the fact that turbine engines can provide substantial power beyond their normal ratings for short periods of time. Although this sacrifices engine life, developing the technology that would allow the use of this capability for short periods under emergency conditions is an attractive alternative. This is particularly true because engines rarely fail and a requirement to remove and overhaul an engine after emergency use may carry a lower cost than carrying excess weight and fuel during the entire life of the vehicle.

The engines of today can typically develop only 10 to 15 percent emergency power. Engine research to develop a 30 to 35 percent emergency capability is required to achieve the necessary levels for civil safety.

One possible method of minimizing the contingency power required is a variable diameter tiltrotor (VDTR) proprotor. A VDTR proprotor can provide different diameters for different flight regimes. A small diameter would be used for cruise flight and a larger one could be used for hover and/or autorotation. A VDTR could (1) reduce the power required in cruise flight, (2) increase autorotation performance, and (3) reduce the power required in hover and slow-speed flight for one or two engines operating. However, it must be noted that these are only potential advantages. The increased complexity resulting from the addition of retraction/extension mechanisms would tend to reduce reliability and increase weight. For this reason, VDTR is only one of many design options potentially available to designers.

3.3 Flight Control Systems

The committee examined the mechanical control system of the XV-15, the triply redundant fly-by-wire (FBW) V-22 control system, and the fly-by-light (FBL) control systems currently being researched.

A traditional mechanical flight control system uses flight control rods, steel cables, pulleys, and bellcranks to move the aerodynamic control surfaces. To provide the kind of redundancy required by the FAA for civil passenger operations with no more than one failure in 10^9 flight hours, an all

mechanical system would probably be far too heavy for an economical CTR.

A FBW flight control system uses electric pulses traveling through wires to carry the control inputs from the cockpit to the actuators that move the aerodynamic control surfaces. It is lighter and much more compact than the purely mechanical control system. The Airbus A330 and A340 aircraft and the Boeing 777 aircraft are flying today with FBW systems that have been certificated by the FAA. The V-22 also uses a FBW system, although this system was not designed to meet civil standards.

A FBL control system uses pulsed light beams traveling through fiber optic cable from the cockpit to the control surface actuators. Such control systems show great potential, but they have not yet reached the maturity necessary for operational use in air transport aircraft. If ongoing research can produce a mature FBL system by the year 2002, potential CTR manufacturers may consider its use.

A significant challenge in the design of any of the above flight control systems is to include an adequate degree of redundancy in the actuators that move the aerodynamic control surfaces. Another challenge is to design the flight control system to inform the pilot which automated mode and what configuration the aircraft is in. The answers to these challenges would be part of the design review and test matrix and would be examined by FAA certification officials.

It is likely that a CTR FBW control system could be designed to meet FAA standards of no more than one failure in 10^9 flight hours if the additional research described in this report is carried out. A detailed description of the CTR flight control system can be found in the Safety Subcommittee report contained in Volume II of this report.

3.4 Internal Noise/Vibration Reduction

3.4.1 Internal Noise

Internal noise does not represent a certification problem, but reduction of internal noise is very important for passenger comfort and acceptance.

The use of noise-absorbing materials on a CTR will aid in reducing internal noise. Passive tuned dampers could be used to further reduce noise levels, although both cost and weight penalties would be incurred. Additional research is required in these areas to minimize weight and cost while maximizing noise reduction.

Active sound reduction is also a potential solution and might reduce internal noise by 50 percent. Active sound reduction systems are divided into acoustic systems that use a canceling sound field from speakers to cancel airborne sound waves, and structural systems that use structural excitation to cancel structure-borne sound waves.

3.4.2 Vibration

An important objective in the design of a CTR is to provide the passengers with very low vibration levels, consistent with their expectation of a comfortable ride equivalent to jet aircraft.

In the helicopter flight mode, tiltrotors experience vibration similar to conventional helicopters. In the airplane flight mode, tiltrotors also experience vibration because the rotor operates in the presence of wing/fuselage aerodynamic flows and because the passage of the rotor blades through this velocity field induces harmonic vibratory responses at the blade passage frequency. A further excitation in cruise flight is due to the wake from each blade flowing back into the tail surfaces.

3.5 Composite Materials

In the past 20 years, there have been great advances in the application of composite materials, such as boron, epoxy, fiberglass, and carbon, to aircraft structures and skins. One manufacturer has successfully manufactured all (approximately 9,000) of its rotor blades from composite material since 1976. Several helicopter manufacturers are now capable of building composite fuselage, wing, and tail structures that are lighter, less expensive to build, and have a reduced parts count than a similar metallic structure. Composites have high potential for use in the CTR.

The primary issues in the use of composite material structures are quality control, extended fatigue life, and failure modes of the composite materials and structures themselves. Since no tiltrotors and few fixed-wing airplanes have been certified with primarily composite construction, research will be needed in this area to support the development of CTR structures technology.

3.6 Manufacturing

The introduction of high-speed computers has completely changed aircraft manufacturing. Companies now design and build aircraft using automated methods to reduce costs, change-overs, redesigns, and manufacturing time. The early use of composites was constrained by design and manufacturing approaches developed for metal structures. These relatively inefficient practices limited the use of composite materials. It should now be possible to apply computer-aided manufacturing techniques to reduce costs, increase productivity, and ensure a high level of quality control during production and fabrication of the aircraft and its component parts.

Automating the manufacturing process through the use of computers and high-speed tooling machines can dramatically reduce CTR production costs. A wealth of knowledge will be gained by examining ongoing NASA and Department of Defense research in this area as well as lessons learned from the V-22 development and production programs.

3.7 System Condition and Usage Monitoring Technology

System condition and usage monitoring systems, often referred to as health and usage monitoring systems (HUMS), are currently being integrated into new aircraft and retrofitted into existing aircraft. Such systems monitor critical flight operational and systems performance parameters and conduct diagnostics on aircraft subsystems such as the engine, the flight control system, and the transmission system. Such technology can be used to monitor the structural integrity of critical airframe components as well as operation of the vehicle by the crew. The flight operations quality assurance (FOQA) data will capture incidents and operational problems that might lead to accidents if not detected by other means. This condition and usage information is recorded for postflight analysis and can be used to extend component lives beyond traditional times between overhauls when supported by sufficient component life data. This type of system is highly recommended for a CTR.

3.8 Autorotation

Simultaneous failure of both engines is a highly unlikely event. But if this should occur while the CTR is operating in helicopter mode, lift contributions from proprotors and wings are expected to facilitate an autorotation to a run-on landing with forward speeds of 50 to 70 knots, in a manner similar to that of a heavyweight helicopter. Should such a failure occur in the cruise mode, a power-off landing similar to that of a turboprop, could be made. In some circumstances, the pilot may be able to make a power-off reconversion to helicopter mode and autorotate to a landing as described above.

3.9 Icing

Icing protection systems similar to those used on the V-22 should be adequate for the CTR. The V-22 uses a conventional pneumatic boot on the wings as well as an electrothermal system . The deice pneumatic boot can be inflated and then deflated to break up and shed ice when it forms on the leading edges of the wings. The anti-ice electrothermal system heats elements embedded in the proprotors, canopy, engine inlets, and windshields to prevent ice attachment.

The effects of using deicing fluids on the composite materials of the aircraft itself will have to be considered and evaluated to determine if the fluids exhibit any corrosive behavior. The use of Type 2 deicing fluids at major airports is expected to become commonplace by the turn of the century.

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4.0 CTR Safety

- The FAA should stay abreast of the latest developments in composite structures and flight controls to assure a seamless certification process.
- Causes of the three previous tiltrotor mishaps involving the XV-15 and V-22 aircraft were not related to the tiltrotor concept.
- U.S. tiltrotor designers are capable of appropriately addressing a variety of potential failure modes, including failure of the engine or proprotor tilting mechanism.
- The CTR is expected to operate to the same safety standards imposed on passenger jet airliners and, therefore, is anticipated to have an excellent safety record.
- CTR aircraft should exploit the Global Positioning System (GPS) and also Operating and Systems Conditioning and Usage Monitoring technology to enhance safety.

The civil tiltrotor (CTR) is envisioned as a versatile aircraft capable of operating from hover to airspeeds of between 350 and 400 miles per hour which is comparable to a modern turboprop airplane. The CTR design represents a combination of characteristics of multi-engine turboprops and turbine-powered helicopters.

The most advantageous characteristic of the CTR is the ability to tilt the proprotors from a horizontal position to a vertical position, converting from a helicopter to an airplane and back again. This is called conversion and it gives the CTR the best features of both a helicopter and a fixed-wing turboprop. The CTR can hover like a helicopter and it also has the speed of a turboprop airplane. The airplane cruise mode provides safety advantages of speed, altitude, and range. The helicopter mode provides the safety advantages of precise approaches at low speed without danger of wing stall.

Figure 4.0-1 shows the conversion sequence as the aircraft takes off in the helicopter mode, converts to the aircraft mode as it leaves the vertiport area, then increases speed and cruises at altitude in the airplane mode. As it nears its destination, the CTR converts back to the helicopter mode, hovers about 10 feet above the vertiport landing area, and then lands vertically. The CTR remains fully controllable about all axes at every point during the conversion sequence. The allowable airspeed range for each angle of the tilting proprotor is large enough to permit great flexibility in piloting the aircraft. This has been demonstrated in flight by the XV-15 and the V-22.

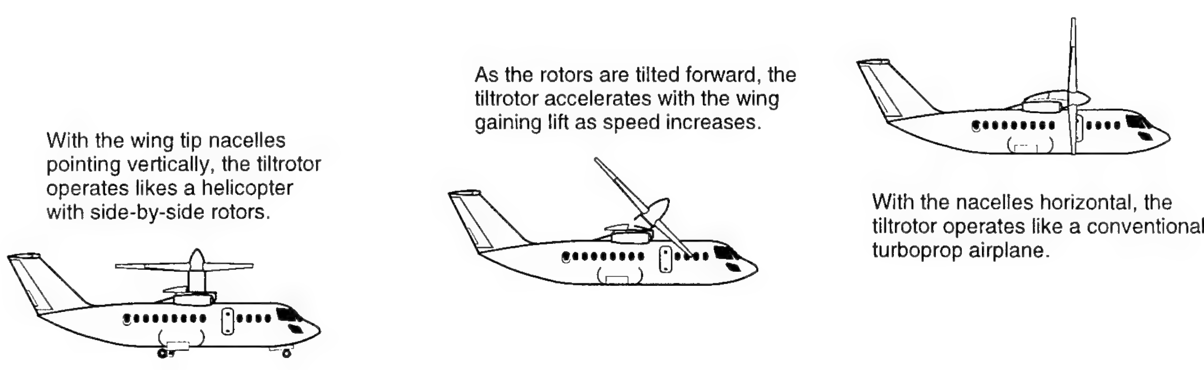

Figure 4.0-1 Tiltrotor Conversion Sequence

4.1 Flight in the Airplane Mode

The CTR will spend the vast majority of its flight time in the airplane cruise mode, retaining the long-range advantage of a turboprop aircraft. This improves the ability of the CTR to reach an alternate landing site during adverse weather. Code of Federal Regulations Instrument Flight Rules, 14CFR91 and 14CFR121, require that an aircraft must carry enough fuel to complete the flight to the first airport of intended landing, fly from that airport to an alternate airport, and then fly for 45 minutes at normal cruising speed. The CTR concept considered by the committee has a 600 nautical mile (NM) range with full passenger load along with IFR fuel reserves for a 50 NM alternate destination and an additional 45 minute cruise.

The CTR pressurized cabin will allow cruise flight to an altitude of at least 30,000 feet, enabling it to fly above most adverse weather patterns and turbulence. The CTR will use IFR procedures and will be flown like a commuter turboprop aircraft, minimizing the risk of terrain or obstacle collisions.

Another advantage that the CTR shares with turboprops is low vibration. This enhances structural and dynamic component reliability and reduces maintenance required compared to a helicopter of similar size.

4.2 Flight in the Helicopter Mode

With the proprotors tilted up so that the rotors are parallel to the ground, the CTR is capable of low speed flight and hover. It has no wing stall speed because the proprotors, rather than the wing, supply most of the lift in low-speed flight. The low-speed and hover capabilities of the aircraft permit it to make slower, safer approaches than are possible for a fixed-wing turboprop and give it excellent low speed and cross wind landing capability.

Because the CTR can tilt proprotors, tilting the lift vector, it can maintain a near-level fuselage attitude for all flight conditions. This greatly increases visibility and is a particular safety advantage during landing, when an airplane or helicopter must raise the aircraft nose to slow down just prior to touch down.

As the tiltrotor converts from low-speed helicopter mode to high-speed airplane mode, commands to the proprotor controls are gradually phased out as the aileron, elevator, and rudder control surfaces become more effective. The control phasing is performed in a manner that maintains a constant level of controllability as the aircraft transitions between modes. This affords the pilot complete control of the aircraft at any proprotor angle between helicopter mode and airplane mode. Such controllability enhances safety by giving the pilot maximum flexibility in flying the aircraft.

4.3 FAA Type Certification

Before introducing a new aircraft into commercial service, manufacturers must obtain a Type Certificate from the FAA, signifying that the basic design and systems meet minimum airworthiness standards. Throughout the design process, the manufacturer must supply the FAA with detailed plans, drawings, test plans, laboratory test reports, and analyses demonstrating compliance of the aircraft with FAA design requirements.

The certification process depends heavily on the expertise of the FAA Designated Engineering Representatives (DER). The DERs are employees of the manufacturer who act as surrogates of the FAA in approving certification tests and analyses. The FAA certification staff oversees these designees, who are specialists in their respective technology areas. A recent Government Accounting Office (GAO) report, however, raises a concern over the lack of FAA experience in certain new technologies.[1]

In an attempt to improve staff competence, the FAA established the National Resource Specialist (NRS) program to develop in-house experts in such areas as crash dynamics, composite materials, and advanced avionics. The Aerospace Industries

[1] Mead, K., "Aircraft Certification, FAA Can Better meet Challenges Posed by Advances in Aircraft Technologies," GAO/T-RCED-94-53.

Association of America (AIAA) responded to the GAO report and recommended that the "NRS for a particular specialty should maintain general oversight of a technology and as it approaches a maturing stage, the NRS should begin to lead the development of reasonable standards for certifying designs with the new technology. Also, the NRS should take a significant role of bringing the FAA certification staff 'up to speed'."[2]

In order to establish well-founded airworthiness criteria, the FAA will need familiarity and experience with the new technologies that may be used in the CTR, especially composites and advanced flight control systems. Requirements for aircraft to meet certification standards do not guarantee safety if the basis for the standards is lacking or the certification evaluation is incomplete. For this reason, FAA involvement in tiltrotor flight safety studies and reviews must continue for the agency to be well versed in the technologies that they will later be asked to certify. The FAA has been working with NASA to define criteria in these areas.

4.4 Failure Modes

The CTRDAC explored a wide variety of potential failure modes to assess the significance of those unique to tiltrotor and those common to helicopters or airplanes. The committee also looked at the three previous accidents of the existing XV-15 and V-22 tiltrotors to see if design changes are required in the CTR. Committee findings are outlined in the following paragraphs.

4.4.1 Engine Failure

4.4.1.1 Single Engine Failure

Multiengine jet airplanes and multiengine turboprop airplanes have a minimum control speed at which it is still possible to control the aircraft directionally with one engine inoperative. With one engine failed, these aircraft experience a large turning force that tries to turn the aircraft steadily in one direction. Significant rudder control is required to offset this, and there is an airspeed below which control is not possible. The CTR does not experience this problem because both rotors are connected by an interconnecting drive shaft running inside the wing. If one of the two CTR engines fails, the interconnecting shaft allows power from the remaining operating engine to be shared between both proprotors. This applies in either the airplane mode or the helicopter mode.

To increase the probability of a safe landing or a safe flyaway, research should be performed to develop a CTR engine with substantially increased contingency engine power. This would ensure that emergency power is available from the remaining engine should one engine fail. Although NASA and industry are currently pursuing this objective, the program should be expanded and accelerated to produce an enhanced engine by the year 2002.

4.4.1.2 Failure of Both Engines

A failure of both CTR engines is expected to be an extremely rare event. The FAA has stated that CTR certification would likely require the aircraft to be treated the same as any two-engine jet or turboprop airplane. To receive FAA certification, a two-engine jet or two-engine turboprop airplane must demonstrate that it can safely land or continue flight following a single, but not a dual, engine failure.

Though not required by the FAA, the CTR would possess an added advantage over the jet and the turboprop airplanes because it will have the ability to autorotate to a helicopter-like landing following the loss of both engines. Following loss of power while in the helicopter mode, the CTR rotors would windmill due to the airflow up through the rotor during the descending flight similar to the way a pinwheel spins as a person runs with it. This windmilling, technically known as autorotation, allows the aircraft to be controlled during the descent. It also stores energy in the spinning proprotors. As the CTR nears the ground, the pilot would increase the pitch on the proprotor blades.

[2] "Improving Aircraft Safety: FAA Certification of Commercial Passenger Aircraft", National Academy of Sciences, June 1980

This would create sufficient vertical thrust, or lift, to cushion the descent and achieve a 50- to 70-knot run-on landing.

If the total power failure occurs in the airplane cruise mode, the CTR would be able to make a run-on landing on a runway. During this landing, the proprotors would be tilted upwards about 35 degrees to avoid contact between the proprotors and the ground. An alternative maneuver, if the situation permits, would be for the CTR to convert to the helicopter mode and then autorotate to a short-field landing.

Although CTR autorotation capability is not required by FAA, it would be prudent to conduct wind tunnel testing to more accurately determine detailed CTR autorotation performance so that autorotation procedures and an optimum proprotor can be developed. Research simulation should be performed to define optimum flight procedures following single- and dual-engine failures.

4.4.2 Failure of the Proprotor Tilt Mechanism

The CTR is designed to take off and land vertically in the helicopter mode. If the proprotor tilting mechanism were to fail while the aircraft was in the airplane cruise mode, the 36-foot proprotors would be too large to avoid ground contact in an airplane-mode landing. Therefore, the proprotors must be tilted at least 35 degrees upward to permit run-on landings on a runway without damage. As a last resort, a safe landing can be made in aircraft mode since the proprotors are designed to shred on contact with the ground without damaging other aircraft components.

For this reason, the tilting actuator must be highly reliable with built-in redundancies. For example, the V-22 tilting actuator assembly is powered by two hydraulic motors with an electric motor backup mode.[3] The actuator design permits at least one-half of full tilt angle during a partial failure of the assembly. The V-22 tilting actuator is controlled by the digital fly-by-wire control system which directs the position, speed, and synchronization of the two pylons. The V-22 proprotor and engine nacelle all tilt together as a unit. The XV-15 and V-22 proprotor tilting mechanisms have never failed. The reliability of this mechanism is clearly important, but the XV-15 and V-22 have shown that industry possesses adequate design capability in this area.

Transmission reliability must also be considered. Due to the need for tilting gearboxes, interconnect shafting, and two proprotor speeds, tiltrotor transmissions are more complex than those found in turboprops or conventional helicopters. It is recommended that FAA NRS personnel closely monitor the development of these systems so their reliability can be assessed for certification purposes.

The variable diameter tiltrotor (VDTR) is an alternate proprotor configuration that would be capable of an airplane-mode landing. The VDTR proprotor blades are retracted to reduce the proprotor diameter in airplane mode flight for better performance. This reduced proprotor diameter could allow the VDTR to land in airplane mode without proprotor damage. The VDTR configuration, however, requires the addition of diameter change actuators. This introduces additional failure modes that would need to be mitigated.

4.4.3 Transmission Secondary Lubrication System

If lubricating oil is lost due to a leaky seal or a cracked case, a secondary lubrication system could minimize the possibility that the transmission will fail before the aircraft can be landed. On the V-22, the secondary lubrication system injects oil from a standby reservoir into the proprotor gearbox, allowing the aircraft to operate for 30 minutes in the event of a loss of oil pressure in the primary system. While this is a part of the V-22 design for added ballistic tolerance, the committee recommends that it be standard equipment on a CTR as a safety enhancing feature.

[3] Hicks, D. and Short, A., "Fail Safety Aspects of the V-22 Pylon Conversion Actuator," Presented at the American Helicopter Society 48th Annual Forum, Washington, D.C., June 3-5, 1992, pp. 1157-1165.

4.4.4 Previous Aircraft Mishaps Involving the XV-15 and V-22

A review of the XV-15 and V-22 mishap histories shows that both configurations have survived several in-flight, single-engine failures or shutdowns and that they successfully operated with one engine inoperative (OEI) as designed. The XV-15, flying well above helicopter speeds, has also suffered a bird strike that seriously damaged a wing leading edge spar, yet the aircraft landed without incident.

Three mishaps have occurred that resulted in the complete loss of a tiltrotor aircraft. The first mishap involved the fifth prototype of the U.S. Navy/Marine Corps V-22 on its maiden flight. The cause of the accident was improper wiring of roll rate sensors in the primary flight control system that caused the pilot control inputs to get out of phase with the aircraft. Since improper wiring of sensors during flight testing can occur in any type of aircraft flight test program, this is not a situation caused by anything unique to a tiltrotor.

The second incident involved the fourth V-22 prototype. A leaky seal in the right engine nacelle allowed combustible fluid to pool in the nacelle. During proprotor tilting, the fluid was ingested into the engine, causing an engine flash fire that damaged the composite interconnect drive shaft (ICDS) which subsequently failed under load. Failure of the ICDS prevented sharing of power between the two proprotors. Leaky seals are not intrinsic to the tiltrotor concept and several design modifications have been installed to correct this problem. There has been no recurrence of this problem. This incident points out the need for a very complete failure modes and effects analysis (FMEA) supporting the design of an extremely reliable engine/transmission system.

The third mishap was the crash of an XV-15 experimental aircraft. A loose bolt in the proprotor control system was cited by the National Transportation Safety Board (NTSB) as the cause. Since the XV-15 was an experimental aircraft, it did not employ double retention of control system attachment hardware as would be required in a certificated aircraft.

The most important feature of these three mishaps is that none was a result of the tiltrotor concept.

The design or maintenance mistakes involved in these tiltrotor mishaps could have also occurred on either a turboprop aircraft or helicopter. However, the broad lessons learned in areas such as reliability, maintenance, and training are as applicable to the design of a future CTR as they are applicable to any advanced aircraft.

4.5 Other Factors Affecting Safety

4.5.1 Flight Control System

In the advanced flight control systems being developed today, the pilot flies the aircraft through a computer. A computer system provides stability augmentation and automated flight modes to reduce pilot workload. If the pilot commands are relayed by the computer electronically to actuators at the control surfaces, the system is called fly-by-wire (FBW). The two major components of these advanced systems are software and hardware. The software includes the algorithms that the computer uses to process pilot commands. The hardware component includes the actuators, power supplies, feedback sensors, and the computer itself. The certification of FBW control systems is one of the areas requiring further definition. The FAA must also develop expertise to provide oversight of software-based systems design.

FBW control systems and digital computers greatly increase the options for flight deck automation and the impact must be well understood. Possible confusion on the part of the pilot over automated mode selection, which has occurred on other aircraft types[4], must be avoided.

Maintaining configuration awareness is more complicated in a tiltrotor since it has two modes of flight control: aerodynamic control surfaces for fixed-wing flight, and proprotor control for heli-

[4] Hughes, D. and Dornheim, M., "Accidents Direct Focus on Cockpit Automation," Aviation Week and Space Technology, Jan. 30, 1995, pp. 52-54.

copter flight. As the aircraft transitions from one flight mode to the other, one control mode is phased out while the complementary mode is phased in. Because the flight computer controls the phasing to maintain a constant level of controllability, the pilot's control wheel no longer provides a direct indication of the position of the control surfaces. In addition, several automated functions may be employed to reduce pilot workload. When these systems are operating, the pilot may not have direct control of the behavior of some of the aircraft systems. FAA personnel must have a thorough understanding of these software-intensive systems to certify that the design of the cockpit, information displays, and mode automation will not lead to pilot confusion.

FBW flight control systems and automated flight decks will require special attention during certification. Further work is required on flight deck human factors research to develop a cockpit that is specifically designed for CTR operations, especially for steep descents into a vertiport. Recently, the FAA has participated in an ongoing NASA simulation study on cockpit display concepts for CTR on steep instrument approaches. These studies looked at the use of flight directors, automated flap control, and semi-automated nacelle movement to reduce pilot workload during steep instrument approach. The Civil Tiltrotor Development Advisory Committee (CTRDAC) recommends continued support of FAA investigations with NASA in this area.

4.5.2 Structural Integrity

Composites were used extensively in the V-22 because of their excellent fatigue properties and because they can be tailored to optimize the properties of a structure. The ability to tailor composites allows structures to meet demanding aeroelastic and vibration requirements. For these reasons and others, use of composites is considered likely on the CTR. Composite materials, however, represent a developing technology with some unknowns regarding the effects of environmental degradation, damage propagation, and processing quality control. Composite materials have also been cited as one of the technology areas in which FAA personnel require additional training so that they can adequately verify regulatory compliance. Much will be learned about composites from experience on the V-22 and other programs, and FAA permanent staff specialists must monitor these developments in order to assist the certification personnel in defining requirements and verifying compliance.

4.5.3 Crashworthy Design Features

Tiltrotors have several significant crashworthy design characteristics, including large mass relief, rollover stability, and reduced pitch and roll attitude upon impact. Mass relief refers to the placement of large mass items such as the engines, gearboxes, and proprotors away from occupied areas. These high-mass items are located on the wing tips and can be designed to fail in a controlled manner during a crash landing. Shedding the wings and pylons during a crash reduces the aircraft mass by approximately 40 percent, which further reduces the crash loads on the fuselage structure. Designing the wing and pylons to fail before the fuselage reduces the probability of the collapse of the passenger compartment.

In a controlled crash, the attitude of a tiltrotor on impact is expected to be nearly level. This maximizes the energy absorbing function of the landing gear and fuselage structure. Tiltrotor wings have a beneficial effect on the roll impact attitude and help to right the aircraft and prevent rollover should the impact occur at a wing-low attitude. In the unlikely event of a rollover, the wing support structure and forward cabin bulkhead should provide a strong rollover structure, preventing fuselage collapse.

These and other crashworthy design features are currently part of the V-22 design and should be incorporated into the CTR.

4.5.4 Crew Training and Certification

CTR pilots are likely to hold either a fixed-wing or a helicopter certificate prior to tiltrotor training. The training syllabus may differ accord-

ing to the background of the candidate. Training/transitioning and pilot qualifications must be addressed because tiltrotor operating characteristics include both helicopter and fixed-wing aircraft characteristics.

Continued support of FAA and NASA R&D studies is recommended. Since the flight decks of fixed-wing aircraft and helicopters have significant differences, the training program and the flight deck human factors research initiative should be closely linked.

Recently, the FAA has published a notice of proposed rule making (NPRM) on pilot, instructor, and pilot school certification rules.[5] Of particular interest is the proposed addition of powered-lift aircraft as a new category for certification of private, commercial, and airline pilots and for flight instructor and ground instructor certificates. These changes are proposed in 14CFR61, Certification: Pilots and Flight Instructors. As CTR aircraft and simulators are certificated and become more widely available, these proposed rules will be used to certificate pilots and instructors.

The Federal Aviation Regulations relevant to operations certification include 14CFR91 (general operating and flight rules), 14CFR135 (commuter air taxi and commercial operators), and 14CFR121 (air carriers). The 14CFR91 regulations are the least restrictive. The 14CFR135 requirements are more rigorous, and 14CFR121 regulations are the most stringent. Even within a single standard such as 14CFR135, there can be operational variations such as requirements for scheduled service using established routes or nonscheduled service to different destinations. General Aviation regulations, 14CFR91 include a wide range of operations or mission types, including personal use and training as well as commercial operations that are exempt from 14CFR135.

Since there are presently no operations certification criteria for CTR in air carrier service, it is recommended that the FAA develop a standard that incorporates those requirements of the appropriate regulations that can significantly contribute to the safety of commercial CTR operations.

By complying with suitable regulations, a CTR providing scheduled air carrier service can be expected to have an excellent safety record. CTR aircraft are expected to have a high airworthiness level and to be operated by well qualified and trained crew members. While conducting scheduled service, the operating environment will be strictly controlled. Flights will operate over well established routes. Finally, by the time it enters service, the CTR should benefit from ongoing improvements in safety enhancing technologies.

Past history indicates that comparable levels of safety can be achieved when the same operating standards and/or regulations are applied to either airplanes or helicopters performing the same mission such as IFR scheduled commuter service. For this reason, the committee expects that a CTR operating under the same standards required of passenger jets will have a similar safety record. A more detailed discussion of CTR safety is contained in Volume II of this report.

4.5.5 Global Positioning System

Global Positioning System (GPS) satellites allow a pilot to know aircraft location precisely. Research by the FAA and NASA is currently underway to develop a ground-based augmentation system to serve as a reliable part of the Air Traffic Control (ATC) system for use by all aircraft including the CTR. They would also be a useful addition to ground- and air-based radar capabilities.

The use of GPS technology for horizontal and vertical navigation and instrument approach/departure procedures is expected to provide the level of navigational accuracy and integrity required to meet safety standards. Using GPS, CTR pilots will have an economical and highly effective method for conducting IFR operations. By the end of this decade, the GPS Wide Area Augmentation System (WAAS) should enable Category 1 operations

[5] Notice of Proposed Rulemaking: Pilot, Flight Instructor, Ground Instructor, and Pilot School Certification Rules, Docket 25910, Notice 95-11, Federal Register, August 11, 1995.

throughout the National Airspace System. Even higher navigational accuracies (Categories 2 and 3) should be possible using a GPS Local Area Augmentation System (LAAS) transmitter near the landing site. The LAAS is expected to have the capability to transmit position corrections to aircraft conducting operations within a 30-mile radius, giving high accuracy and enhancing instrument approach safety. Both of these augmentation systems are known as differential GPS (DGPS).

Conventional radar-based methods for positive control of low-altitude CTR air traffic could be cost prohibitive. In metropolitan areas, a significant number of additional radar systems would be necessary to provide sufficient coverage due to interference of buildings and terrain. However, the required level of safety for a positive control environment is expected from automatic dependent surveillance (ADS) based on GPS position data linked to an ATC facility via satellite or ground-based repeaters. An experimental satellite-based ADS system is now providing a positive control environment for transoceanic flights which allows traffic spacing to be reduced significantly while maintaining the required level of safety.

4.5.6 Systems Condition and Usage Monitoring Systems

Systems condition and usage monitoring systems, often referred to as health and usage monitoring systems (HUMS), are currently being integrated into new aircraft and retrofitted into existing aircraft. Such systems monitor critical performance parameters and conduct diagnostics on aircraft subsystems such as the engine, the flight control system, and the transmission system. Such technology can be used to monitor the structural integrity of critical airframe components. This condition and usage information is recorded for postflight analysis and can be used to extend component lives beyond traditional times between overhauls when supported by sufficient component life data. This type of system is highly recommended for a CTR.

4.5.7 Flight Operations Quality Assurance

Since crew error is cited as a factor in the majority of accidents, the aviation community has always looked for ways to improve crew performance. Several foreign and U.S. airlines are beginning to analyze recorded flight data as a means of detecting latent errors in crew and other human performance. This allows the airlines to identify human and procedural errors in the aircraft and ATC operations. This can also provide timely feedback to flight crews on recent performance and to identify training requirements, operating procedural changes, and trends for the entire airline industry. This process has been termed flight operational quality assurance (FOQA).

Because FOQA is more easily implemented in new aircraft with digital data buses and sophisticated monitoring systems, CTR would be a good candidate to benefit from the potential increased crew performance associated with this technology. CTR operators providing scheduled service should adopt a FOQA program.

4.5.8 Ground Operations

One potential hazard from proprotors turning during ground operations is rotorwash. During ground operations, the downdraft from the proprotors impacts the ground surface and is turned horizontally. Because the tiltrotor rotorwash velocities are typically higher than those of a small helicopter, the potential for adverse effects on personnel and equipment is also higher.

An additional concern is flying debris driven by the rotorwash. While wearing protective eye wear can reduce potential danger, this solution is expected to be unacceptable for civil airline and general aviation operations and for passengers boarding the aircraft.

If proprotors are kept turning during gate operations, proprotor thrust and resulting downwash must be kept to near zero. If this is not possible, the high rotorwash velocities may require the use of

loading bridges similar to airport jetways to protect passengers boarding or exiting the aircraft. The need for loading bridges may be further driven by other tiltrotors maneuvering and taxiing in the vicinity of one that is boarding or unloading. Addressing this concern within the restricted land area at a vertiport is expected to drive both operational procedures and vertiport design requirements.

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5.0 Environmental Impacts

- Noise is the most critical environmental issue for CTR acceptability.
- Significant further research will be required to bring CTR noise down to levels likely to be necessary for community acceptance.
- Introduction of CTR services might produce a small increase in energy consumption and emissions, but these might be offset by reductions in delays at congested airports and reductions in CTR passenger access/egress time.
- Development of vertiports will be subject to the same broad range of environmental regulations and approvals as other transportation facilities.

5.1 Introduction

An essential element in successfully introducing civil tiltrotor (CTR) services into the national transportation system is the development of an airspace and ground infrastructure adequate to complement fully the capabilities of the new aircraft technology. CTRs can be viable only with properly designed vertiports, located primarily in urban and suburban areas. Convenient, easily accessible terminals are the key to realizing CTR market potential, but building these terminals requires a satisfactory solution to all environmental concerns of the affected communities. Previous studies have identified environmental acceptability as critical to the establishment of a successful CTR-based transportation system.

CTR technology and services must meet the same environmental requirements that apply when any major transportation system is established or modified. The National Environmental Policy Act of 1969 and Executive Order 12898, "Environmental Justice," are particularly relevant to this issue. The mostly urban location of vertiports imposes significant challenges in planning, design, and development to achieve acceptance in high-density environments.

Community acceptance of vertiports is key to the viability of the CTR. For the CTR to be compatible with local community requirements, CTR external noise levels must be well below those of the V-22. Noise is the single most important aspect of CTR environmental compatibility.

This chapter describes the principal impacts of a CTR transportation system on the environment and the most likely means of impact mitigation. Many such concerns can arise in establishing any transportation-related facility but only issues related to the specific nature of CTR are addressed here.

5.2 Noise

Noise is the most critical environmental issue facing scheduled CTR passenger service. Industry is working to make the CTR as quiet as practical. One key to reduced noise is the design of an advanced rotor system. Instead of the three-bladed rotor design of the V-22 that results from military shipboard compatibility requirements, the CTR rotor is expected to have more than three blades of an advanced design, enabling it to operate at reduced tip speed.

Although noise reduction technology research is being performed by the National Aeronautics and Space Administration (NASA) and industry, the present pace of acoustic research is too slow to produce the results needed for CTR in the next decade.

Noise certification standards applicable to powered-lift aircraft have yet to be developed by the Federal Aviation Administration (FAA) or the International Civil Aviation Organization (ICAO). As with any new aircraft type, it is understood that such specific standards will not be developed in

time to influence the design decisions that must be addressed in the development phase. However, there already exists a powerful requirement in the Federal Aviation Act that mandates the incorporation of noise abatement technology into the design of all new aircraft type certificated by the FAA. Specifically, one part of that act prohibits the FAA from issuing an original type certificate for any aircraft, regardless of whether noise certification regulations already exist, if the FAA finds that the manufacturer has not incorporated all technically feasible and economically reasonable noise abatement technologies appropriate for the aircraft design. This finding by the FAA must be made for the CTR prior to the issuance of its type certificate even if noise certification standards are already in existence for that aircraft type. This requires the manufacturer to incorporate "all" technically and economically available noise abatement technologies, as opposed to the implied requirement under the Code of Federal Regulations (CFR) that the manufacturer need only incorporate those noise abatement technologies necessary to meet 14CFR36 noise limits.

The noise issue is directly linked to infrastructure considerations such as vertiport design and siting, and flight operations procedures. Noise impact depends not only on aircraft characteristics but also on the way the vehicle is operated and the use of the land over which it flies. Preliminary results of noise "footprint" predictions indicate that the smallest practical noise impact areas result from segmented approaches. For this reason, another key to reducing CTR noise is to have the CTR approach the vertiport using a glidepath that is well above the normal fixed-wing 3-degree approach angle. A multi-segmented, multi-angle approach in the vicinity of 9 degrees is likely. The CTR would then transition to helicopter mode for vertical landing at the touchdown spot. This reduces the noise level during the approach and tends to concentrate much of the noise impacts within the vertiport boundaries.

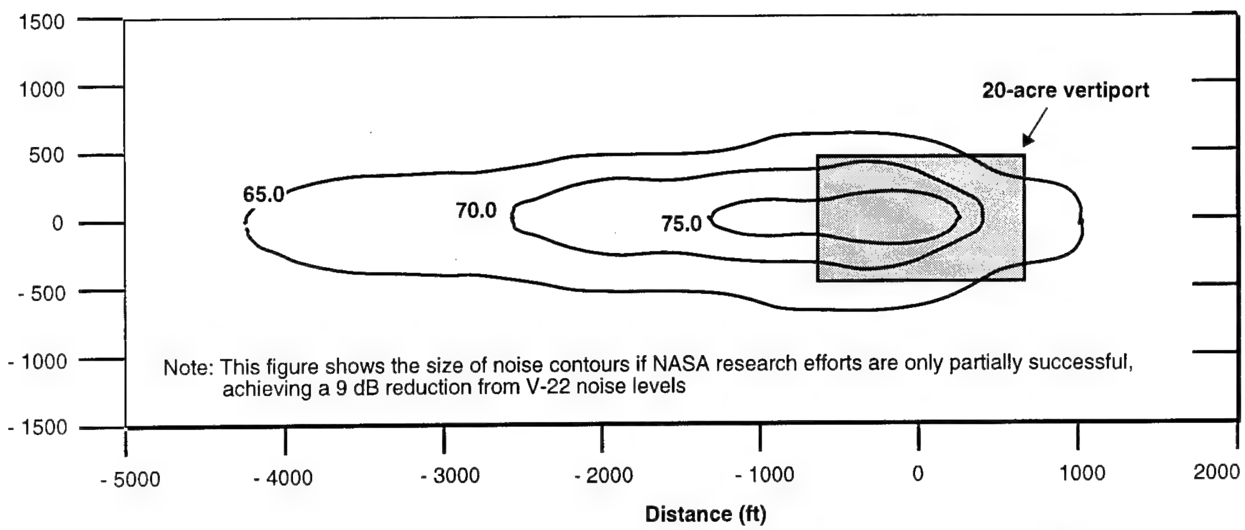
As with any aircraft operation, noise associated with the CTR affects acreage around the actual vertiport facility. For planning purposes, this area can be estimated in terms of a noise metric that combines the frequency of flights, time of day, aircraft noise characteristics, and pattern of operations. Based on the current estimates of CTR noise emissions and terminal operating procedures, it is possible to determine a CTR "noise footprint" day-night sound level (DNL) contour pattern using the same procedure used for other aircraft types and other transportation noise sources. Under the Federal Aviation Regulations, 14CFR150, the generally accepted DNL values are 75 dB for industrial areas, 70 dB for business-use land, and 65 dB for land used for residential purposes. However, the methods and metrics currently used to assess aircraft noise around airports may not be adequate for CTR and heliport land use planning and regulation development.

Using the current CTR conceptual design, a full-scale vertiport built in a business environment would cause a noise impact over an area of approximately 44 acres, assuming 50 approaches and 50 departures per day. This figure is calculated from the DNL 70 dB contour and includes 20 to 30 acres for the actual vertiport. Figure 5.2-1 shows how the area of adverse noise impact changes with different levels of vertiport activity and different DNL contours. Figure 5.2-2 shows a comparison of noise contours for a 20-acre vertiport. The NASA research goal for CTR noise reduction is 12 dB below the V-22 levels. To provide a conservative assessment of noise impact, this analysis assumes that the CTR will achieve 9 dB noise reduction over V-22 levels. If research efforts are successful in lowering the CTR noise by an additional 3 dB, the footprints would be reduced by almost 50 percent (figure 5.2-3). These values are sensitive to several

Daily Approaches & Departures	Industrial (DNL 75)	Business (DNL 70)	Residential (DNL 65)
25	5 acres	21 acres	63 acres
50	**12 acres**	**44 acres**	**119 acres**
100	30 acres	79 acres	214 acres

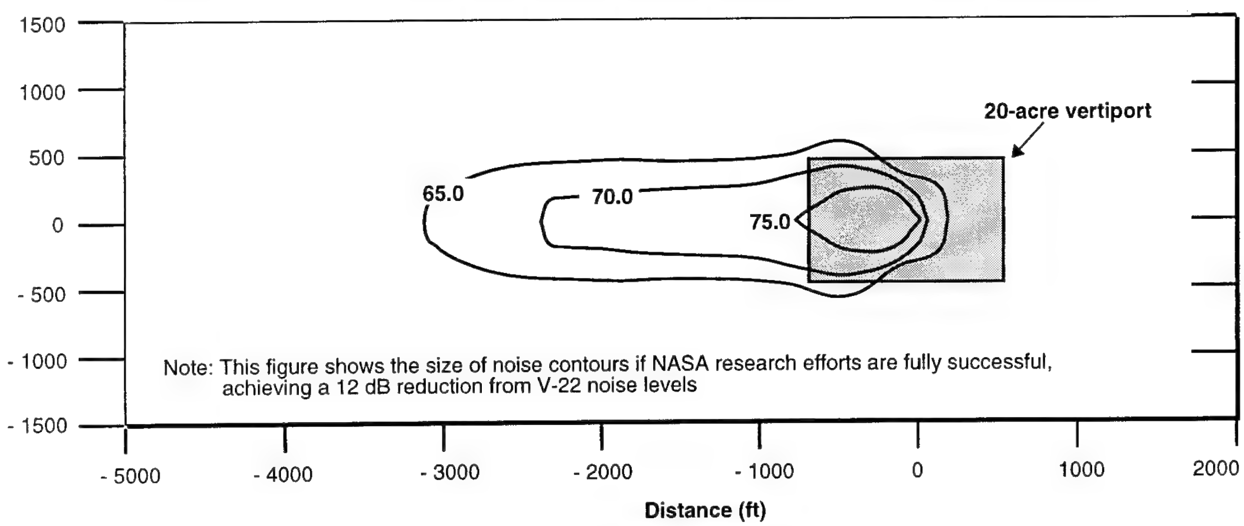
NOTE: CTR 9-degree segmented approaches; approach/ departure on same heading

Figure 5.2-1 Noise-Affected Area By Type of Land Use



Segmented 9-degree approaches; 50 daytime approaches and 50 daytime departures; 5 rotor blades with 740 fps tip speed

Figure 5.2-2 CTR Aircraft DNL Noise Contours Assuming 9 dB Noise Reduction



Segmented 9-degree approaches; 50 daytime approaches and 50 daytime departures; 5 rotor blades with 740 fps tip speed

Figure 5.2-3 CTR Aircraft DNL Noise Contours Assuming 12 dB Noise Reduction

variables, including CTR operating weight, number of proprotor blades, and proprotor tip speed.

The information in figure 5.2-1 is a rough approximation. The local topography and land use surrounding each individual vertiport will affect the situation for each site. In addition, detailed CTR performance and noise characteristics data do not yet exist. For these reasons, current aircraft noise prediction procedures do not provide a fully satisfactory basis for accurate estimation of community response to helicopter and CTR noise, or for related land-use planning and control. The noise produced by a tiltrotor is not directly analogous to that produced by either fixed-wing aircraft or helicopters. Due to the location of vertiports and the relatively large size of the tiltrotor, the committee expects a heightened community sensitivity to noise from CTR landings and takeoffs.

A complication affecting this subject is that conventionally accepted values for the percentage of people who are highly annoyed by certain noise levels have recently been questioned by responsible organizations such as Transport Canada. Current NASA research and development (R&D)

efforts include initial subjective test of acceptance of noise with various spectrum signatures.

The noise issue also has another component. Community reaction to building vibration and rattle produced by rotorcraft is not fully understood. Studies of human response to helicopter fly over noise have shown a difference in subjective response depending on the presence or absence of vibration and rattle in structures and structural components such as window panes. Subjective human response while indoors is strongly and negatively influenced when an outside source of noise induces noticeable vibration and rattles. Such vibrations and rattles can be induced in buildings by the low frequency acoustical emissions of helicopters.

During takeoff and landing, a CTR may have the same potential for inducing structural vibrations as a helicopter. CTR designers and community planners must consider the possibility of greater community resistance to CTRs than predicted by current analytical models for airplane noise. CTR designers may be able to mitigate this problem by altering the acoustic emissions to avoid frequencies that cause structural responses. Being aware of this effect, community and transportation planners would be able to minimize its impact by locating vertiports and designing CTR approach and departure paths to avoid noise-sensitive areas.

5.3 Energy and Emissions

The other two major environmental concerns associated with the introduction of CTR service are energy use and emissions. The two are closely related since emissions result from the combustion of fuel and, therefore, are driven largely by CTR fuel efficiency characteristics.

5.3.1 Energy Use

Market analyses indicate that CTR will likely divert a substantial number of intercity passengers from other modes of transportation, principally jet and turboprop air travel. Because the CTR is expected to use different amounts of energy per seat-mile and produce emissions differing somewhat from those of other intercity passenger modes, the introduction of this new service will have implications for the total amount of transportation energy used and emissions released into the environment.

The analysis of this issue is based on assumptions concerning energy factors for typical jet and turboprop aircraft and likely CTR engine capabilities. Estimates of the resulting energy and emission impacts take into consideration the projected changes in demand for CTR and other intercity passenger transportation modes. Figure 5.3.1-1 shows the energy efficiency per seat-mile of CTR compared to jet and turboprop aircraft that might be in service in the early part of the next century. With expected improvements in engine design, CTR is projected to be about as efficient as modern turboprop aircraft in the same 35- to 60-passenger range. However, CTR will likely use approximately 30 percent more energy per seat-mile than a small jet transport such as the 130-passenger Boeing 737-300 at a typical range of 300 miles.

The diversion of air passenger traffic to CTR service might result in significant offsetting energy savings from reductions in delays at congested airports. These savings would only be realized for delays during the in-flight or ground idling phases of flight. The FAA estimates that airborne delays account for 29 percent of total delays. Ground delays account for 64 percent with the remaining 7 percent caused by gate-hold delays. The energy savings from airport delay reductions resulting from substitution of CTR for jet and turboprop service are estimated to be about the same as the added CTR energy use and might possibly yield a net savings in total energy consumption.

Another possible offset to the estimated increases in energy use for the line-haul portion of CTR trips would be a decrease in projected energy use for the access and egress segments of these intercity trips. These energy savings are based on the assumption that vertiports will be more conveniently located than existing airports. However, the access/egress energy savings are estimated to be only about 5 percent of the estimated line-haul

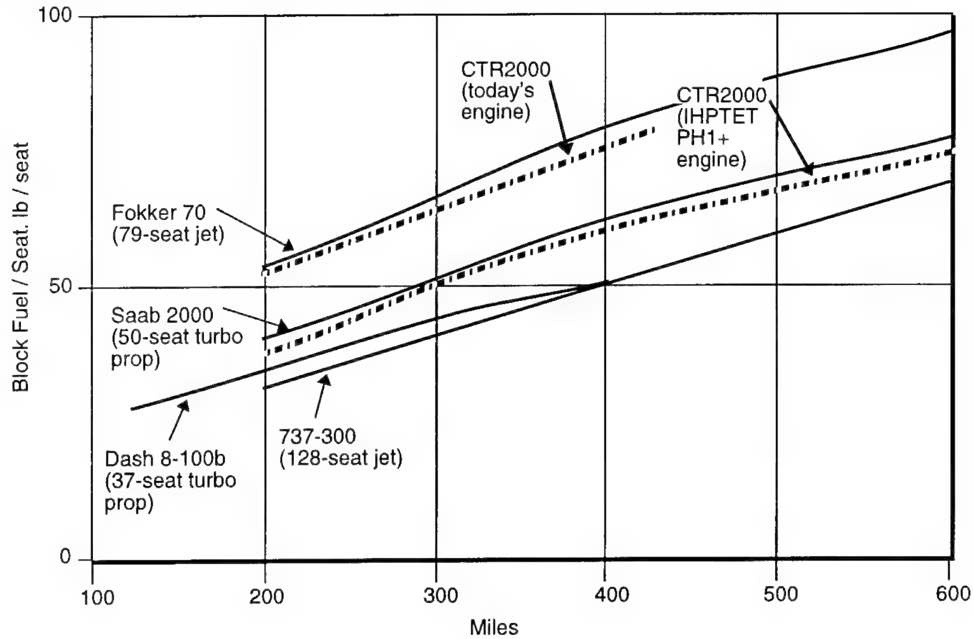


Figure 5.3.1-1. Comparison of Block Fuel Per Seat of CTR Versus Other Aircraft For Different Trip Lengths

energy consumption increases attributable to introduction of CTR service in 2010.

The committee estimated the change in total energy consumption associated with CTR services several years after their introduction. The year 2010 was used for this analysis in each market area studied, including Northeast, Midwest, West Coast, and Southwest. There will be essentially no change in energy use for passengers diverted from conventional commuter flights. The only real impact will be associated with diversion from jet transports, and for additional trips encouraged by the availability of CTR service. The analysis considered only fixed-wing aviation activity between major metropolitan areas and corresponding CTR vertiport-to-vertiport travel. It was assumed that energy consumption of a Boeing 737-300 would be typical for jet travel in the year 2010 and that energy consumption of a Saab 2000 would be typical for turboprop energy use. For these markets, total commercial air travel energy consumed in the CTR markets is projected to be about 5 percent greater with CTR service compared to conventional services only. This impact differs substantially by location with an 18 percent increase in the Northeast Corridor compared to only 2 to 4 percent elsewhere. This is due to the much higher rates of diversion from jet transports anticipated in this region. It also reflects a higher rate of additional flights encouraged by CTR availability in the region that is estimated to represent 10 percent of CTR passengers.

With an initial fleet of 200 CTRs in a total U.S. air carrier fleet of over 6,600 aircraft and 6,200 regional commuter aircraft, tiltrotors will represent only a very small fraction of the total passenger-miles and seat-miles delivered nationally. As a result, the modest reduction in energy efficiency brought about by the introduction of CTRs will produce at most only a negligible increase in total U.S. air passenger transportation energy consumption. As noted previously, compensating factors might eliminate even this modest effect.

5.3.2 Emissions

The rate of emissions per pound of fuel burned varies with engine technology and phase of flight. The CTR configuration used in this study includes an advanced Allison T406+ low-emission engine. Compared to current conventional technology, this unit is expected to produce a 40 to 50 percent reduction in the emissions of oxides of nitrogen in all phases of flight and reduced carbon monoxide (CO) and hydrocarbon (HC) emission rates while

idling (e.g., taxi in/out). Compared to the Boeing 737 jet engines, the CTR engine is expected to produce a smaller amount of oxides of nitrogen, but considerably more HC emissions per pound of fuel consumed. Overall, CTR impact on emissions would be comparable to the percentages noted above for fuel usage.

As in the previous discussion of energy consumption, a reduction in delays resulting in CTR service would compensate for the somewhat higher level of CTR in-flight emissions. Overall, there could even be a net decrease in emissions. For this reason, if airport delay reductions are realized, the introduction of CTR service can reasonably be expected to be environmentally neutral. Even without significant airport congestion relief, the extra environmental burden associated with CTR use is estimated to be minimal.

Environmental requirements, however, are dynamic in nature, changing periodically as a result of scientific, technological, and economic findings and their effect on public perceptions and values. As U.S. and international emissions regulations for civil aircraft become more stringent, the CTR will be required to meet these requirements. In addition, the CTR may be required to meet unique environmental regulatory regulations established by state or municipal governments.

During development of the CTR, there are two factors that may cause either the Federal Government or metropolitan areas to take a stricter approach to emissions. National requirements for reducing CO_2 emissions, which may be called for before the end of the decade under the 1992 United Nations Convention on Climate, may trigger a reexamination of all transportation modes that use fossil fuels. To relieve traffic congestion and meet regional requirements under the Clean Air Act, metropolitan areas may also be forced to make hard choices on their transportation investments.

5.4 Legislative and Regulatory Considerations

Community acceptance issues could be adversely affected as a result of changes in Federal programs. Until recently, the Departments of Housing and Urban Development (HUD) and Veterans Affairs (VA) had mortgage insurance programs in place that provided incentives for local compatible land-use planning in the vicinity of airports. As a result, neither HUD nor VA mortgage insurance was available for housing built in areas impacted by airport noise. These programs helped to discourage incompatible development in the vicinity of airports. In the absence of these programs, investments in airports are at risk from encroachments that may prevent the facility from delivering the full benefits that would otherwise be possible.

During the last two decades, numerous Federal laws and regulations addressing environmental impacts have been enacted. Although all of these will be applicable to the proposed CTR system and to individual vertiports, no issues unique to the CTR are expected to emerge.

Surface transportation legislation and aviation legislation may not be fully compatible, and this may become an issue. In all likelihood, a CTR-based scheduled passenger service system would not be built unless it is part of a regional transportation plan. Facilities will not be built unless there is agreement by the Metropolitan Planning Organizations (MPO) and each of the municipal and regional areas supports the project throughout the planning phase. This type of planning and review would serve to legitimize the need for vertiports.

Due to the urban location of vertiports and the potential for their integration into an intermodal transportation system, the vertiport planning process should be included as an element of city intermodal transportation system planning. To this end, it is critical that vertiport planning be integrated into the Intermodal Surface Transportation Efficiency Act (ISTEA) and MPO processes.

Current FAA vertiport policy limits additional planning studies and places restrictions on Airport Improvement Program (AIP) grants for tiltrotor/vertiport planning. Continuation of this policy would severely hamper the orderly introduction of CTR aircraft and vertiports into the national transportation system.

6.0 Infrastructure

- Community acceptance of vertiports is critical, because locating vertiports close to passenger demand centers is essential to CTR success.
- Ground-level vertiports will require 20 to 30 acres; elevated vertiports will require 10 to 20 acres.
- Vertiports will need to be sited at locations where there is 10 to 119 acres of compatible land use.
- Planned air infrastructure can support CTR with minor modifications.
- Adequate interim regulations exist for tiltrotor aircraft certification, but new regulations will be needed before commercial service could begin.
- Initial construction of vertiports may require public or private loan guarantees to obtain financing from private capital markets.
- Vertiports may be largely self-financing using typical sources of airport revenue, including passenger facility charges and Airport Improvement Program funds.

6.1 Introduction

The infrastructure necessary to support a short-haul civil tiltrotor (CTR) transportation network is comprised of both ground and air system elements. This section addresses community acceptance, site selection, compatible land use planning, ground and air infrastructure, facility design, construction, and operating regulations. This section also examines the economics of a system of vertiports and the means by which vertiports may be financed.

6.2 Community Acceptance

Since the economic viability of the CTR will be dependent on the location of landing facilities in urban and suburban areas, community acceptance will likely be the single most critical issue in developing the required infrastructure. For a community to accept a CTR vertiport, it is essential that they be sited in a location that minimizes the societal and environmental impact and the amount of land required. It is also essential that the public perceives that vertiports are safe and that vertiport sites have been chosen wisely.

While community participation will not ensure acceptance, it is a key element that should be incorporated into the earliest stages of vertiport planning to promote public acceptance. The public should be kept advised of the requirements for, and benefits of, a CTR system as part of a general awareness of the need for a systematic approach to planning for public transportation. Public reaction to CTR noise, safety, and flight operations will significantly affect system planning and design. Public acceptance of CTR for scheduled passenger service in urban or suburban settings may depend heavily on the degree to which CTR is perceived as a community asset, rather than a liability.

A demonstration of actual CTR flight and environmental characteristics in selected cities would clarify its potential and could aid in evaluating the degree to which the public will accept and support this new technology.

6.3 Ground Infrastructure

Vertiports are the basic component of the CTR ground infrastructure system. To support scheduled passenger service, a vertiport would have to operate in all weather conditions and have one or more touchdown and lift-off surfaces (TLOF), multiple-gate passenger terminals, associated rental car and parking facilities, CTR fueling, and limited maintenance capabilities. It is envisioned that vertiports could accommodate CTRs of various sizes for passenger and small package cargo. They would also accommodate helicopters performing a variety of missions over a shorter range than CTR. Vertiports are likely to provide most of the same passenger-oriented services as conventional hub airports. Thus, while vertiports will be physically

smaller than hub airports, they will probably be comparable in facility sophistication.

6.3.1 Design Issues

The design of vertiports is currently addressed by Federal Aviation Administration (FAA) Advisory Circular 150/5390-3, "Vertiport Design" (May 31, 1991). However, recent research initiatives by the FAA and the National Aeronautics and Space Administration (NASA), as well as advances in technology leading to an increased understanding of CTR capabilities, indicate the need to update this document. Critical vertiport design issues that are not yet discussed in sufficient detail in the existing Advisory Circular include:

- Rejected takeoff requirements.
- Facility design features that support safe one-engine-inoperable operations.
- Rollway length and facility sizing requirements as a function of altitude and temperature.
- Characteristics of the baseline CTR aircraft design that should be used in sizing vertiport facilities.
- Development of a methodology for defining vertiport capacity.
- Design standards for surface pavements in which high-temperature engine exhaust may be directly aimed at the pavement during CTR hover operations.
- Passenger services, baggage handling, fire and rescue equipment, security, fueling, deicing/anti-icing, hangars, parking, and fuel storage.

In addition, noise criteria for land use planning need to be extensively examined for their impact on vertiport design and operational procedures. Analyses of noise must address the impact of all types of aircraft (i.e., CTRs, helicopters, and general aviation aircraft) that will be operating from off-airport vertiports or vertiports incorporated into commercial and general aviation airports.

6.3.2 Vertiport Planning and Land Use

A well planned system of vertiports is central to the successful introduction of CTR into civilian service. Such a system must take full advantage of the lessons learned in the last five decades of airport planning, with particular attention to land-use compatibility and quality of life considerations for communities.

A critical aspect of planning is that individual facilities must be situated in favorable locations, with their number and size determined by the demand for such service. Once demand is confirmed, other issues regarding siting need to be addressed. Key considerations include community acceptance, type of ownership, land-use compatibility, zoning, and land acquisition. Although most land-use regulations are administered and applied at the local level (i.e., cities, towns, counties, etc.), planning for a vertiport system would require a cooperative effort among Federal, state, Metropolitan Planning Organizations (MPO), and local government agencies.

In order to provide the capacity needed to handle the number of passengers required to make a scheduled air carrier system feasible, a typical ground-level vertiport will require from 20 to 30 acres. An elevated or multilevel facility can be expected to require 10 to 20 acres. Vertiports will also require that a significant surrounding area be restricted through zoning or other compatible land-use to mitigate noise impacts. Some of this acreage may consist of stable, compatible land use such as rivers, lakes, flood plain, rail yards, industrial parks, etc. The size of this surrounding area will depend on the nature of the adjacent land use and range from approximately 12 to 119 acres.

Noise protection areas of 119 acres in close proximity to passenger demand centers may be very difficult to obtain. Smaller size sites are somewhat less difficult to find. While the amount of land required for vertiports is much less than those for a conventional airport, locating the vertiport near the demand center is expected to be a challenging task in some cities.

An appropriate approach to the development of CTR infrastructure may be to build vertiports in phases. This could be done both for individual facilities and for networks. The heliport on top of the Dallas Convention Center facility is an example of how this could be accomplished for an individual site. In the first of several phases, this facility, funded by the Airport Improvement Program (AIP), was designed and constructed as a large, public heliport. In the next phase, this landing site is designed to be expanded to a public vertiport.

6.4 Air Infrastructure

Air infrastructure issues focus on how the CTR will operate within the current and future air infrastructure systems. These concerns encompass CTR impacts on terminal and en route airspace capacity and productivity, and any changes that may be needed to airspace communication, navigation, surveillance and control procedures, or to aviation regulations.

CTR operations are expected to be integrated into the airspace system that is in place at the time service is initiated. For the most part, CTR is expected to be handled in the en route system like a modern-day, high-performance turboprop aircraft. Preliminary analyses by the FAA[1] indicate that CTR can be accommodated, and its unique capabilities used to advantage, in the existing terminal and en route air traffic control (ATC) environment with minimal impact. It is not likely that the introduction of CTR service will cause significant impact on controller workload or lead to overloaded sectors in or around terminal airspace.

Both the global positioning system (GPS) and automatic dependent surveillance (ADS) technologies add a new dimension to the ATC system and should be well suited to CTR operations. These systems are expected to augment the unique operating characteristics of the CTR that enable it to operate to and from urban and suburban vertiports. No other revisions to basic air traffic systems other than these are considered essential to support CTR air carrier services. These technologies are included in the FAA research and development program and are expected to be available at the time of the earliest introduction of CTR technology.

6.5 Aviation Regulations

Vertiport development is subject to numerous regulations at the Federal, state, and local levels. These regulations affect the land-use, zoning, financing, design, construction, and operation of the vertiport facilities. Of particular importance will be those regulations relating to land-use compatibility and environmental impact.

Some states have specific heliport regulations that are separate from airport regulations, but the majority do not. Nevertheless, even those states not directly concerned with heliports may affect the development of vertiports through a variety of statutes and regulatory requirements pertaining to environmental issues. At a minimum, municipal regulations may encompass permits, land use, zoning, fire protection, operation control, safety, insurance, etc.

The Code of Federal Regulations (CFR) will affect vertiport establishment, operation, and maintenance. The extent of Federal regulation is dependent on the type of ownership (public or private); use of Federal grants; and the type of aviation operations to be conducted, e.g., private or scheduled air carrier. At a minimum, vertiports providing scheduled air carrier service can be expected to be regulated by Code of Federal Regulations, 14CFR77, "Objects Affecting Navigable Airspace;" 14CFR107, "Airport Security;" and 14CFR139 "Certification and Operation: Airports Serving Civil Aviation Board (CAB) Certified Air Carrier Aircraft."

[1] Trigeiro, W.; Szebrat, X.; Fraser, S.; "Effects of CTR Service in Northeast Corridor on En Route Airspace Load," MITRE CAASD, DOT/FAA/AOR-100/94/008, October 1994.

Rakas, J.; Mondoloni, S.; Pernigotti, N.; and Weiss, W.; "Civil Tiltrotor Terminal Area Route Feasibility Study", CSSI, Inc., DOT/FAAASD410-95-002, April 1995.

Airspace limits surrounding airports are described in 14CFR77. Objects that penetrate those surfaces are classified as obstructions and require an aeronautical study to identify the actual effect on navigable airspace. This regulation does not specifically mention vertiports, and its coverage of heliports is in need of revision.

A scheduled air carrier airport or vertiport must meet the security requirements of 14CFR107 for a method or procedure to control access to the secured airport areas to ensure that only authorized persons are able to enter.

14CFR139 prescribes rules governing the certification and operations of land airports that serve any scheduled or unscheduled passenger operation of an air carrier using an aircraft with a seating capacity of more than 30 passengers. Any airport in this category must apply to the FAA for certification. Under 14CFR139, airport operators are required to establish an airport certification manual containing procedures that address airport personnel, paved and unpaved areas, safety areas, marking and lighting, snow and ice control, aircraft rescue and fire-fighting, handling and storing of hazardous materials, airport emergency plans, self-inspection programs, ground vehicles, obstruction removal, protection of navigational aids, public protection, wildlife hazard management, airport condition reporting, and handling noncomplying conditions.

Some vertiports are likely to be located at major airports with existing ATC towers. At other vertiports, ATC services are expected to be provided by existing towers in the same geographic area. At some vertiports, however, the number of operations are likely to require an on-site tower. FAA criteria for establishing vertiport control towers need to be developed.

6.6 CTR Infrastructure Research and Development

Further research and development is necessary in vertiport design criteria, air traffic pattern procedures, aircraft separation standards, and analysis of potential wake vortex/rotorwash hazards that CTR aircraft might create as well as the definition of operational procedures to alleviate those potential hazards.

Currently, there is limited information on the size of the terminal instrument procedures (TERPS) airspace that would be required to accommodate CTR approach and departure procedures. There is also limited information available on the detailed methodologies needed to analyze how such procedures may impact existing airspace or air traffic patterns for both visual flight rules (VFR) and instrument flight rules (IFR) operations. Information on these topics should be developed and provided in the appropriate FAA publications.

Preliminary studies by FAA, NASA, and industry have demonstrated that issues associated with CTR steep-approach field-of-view and approach lighting present a greater challenge than the same issues associated with the typical 3-degree approach angle. Potential transfer of Department of Defense (DoD) technology to civil applications seems to offer elementary lighting and visual recognition systems that might be used for vertiport instrument and visual approaches. Conventional or modified approach light systems may not be adequate to support 9-degree CTR instrument approaches under Category 2 and 3 weather minimums. Technology other than lighting may be required to support such operations. TERPS will need to be developed considering CTR characteristics and GPS receiver design. CTR GPS receivers may need special adjustments in display sensitivity.

Criteria for establishing and operating control towers (class D airspace) at vertiports need to be developed. Preliminary assessments support the need for some level of air traffic authority compatible with these potentially high-activity facilities. Detailed guidelines should be developed for implementing and designating the appropriate airspace at vertiports when the facilities lie under already existing controlled airspace.

Techniques for analyzing airspace impacts need to be refined and standardized, particularly on

high-density rotorcraft operations in the vicinity of proposed vertiports. This should be done both for stand-alone facilities and for facilities located on airports. The FAA should provide guidance on how to assess impacts on local and regional airspace if controlled airspace is instituted around a vertiport. This is of particular concern in an area like Manhattan, since there is a significant amount of VFR traffic along the rivers which are considered potential vertiport sites.

6.7 Costs, Revenues, and Financing

Two important considerations in the potential use of CTR technology are costs and revenues. Cost elements have been examined at two levels. The first level involves the individual facility itself, whether a stand-alone vertiport, a separate facility on an airport, or the existing runways and terminal facilities. The second level involves the of cost of a complete system of vertiports. Also addressed are potential revenues that can be expected from the vertiport and how well these revenues meet the cost of its development and operation.

6.7.1 Vertiport Costs

Figure 6.7.1-1 presents a generic range of costs for different types of CTR facilities at three different locations. The costs are based on the size of specific vertiports, the expected number of passengers, location (urban, suburban, or airport), and type (elevated, ground, or pier). Typical land costs are included.

Location	Type	Cost Range (in millions of dollars)
City center	Elevated vertiport	10 to 40
	Vertiport on new pier	90 to 125
Suburban	Ground vertiport	6 to 20
	Elevated vertiport	10 to 25
Airport	Existing facility	0 to 10
	New airside facility	2 to 17

Note: Cost ranges do not include the cost of noise or environmental mitigation

Figure 6.7.1-1 CTR Generic Vertiport Cost Range

Corridor	Ground Level	Elevated	On Piers	Total	At Existing Airports
Northeast	6	3	3*	11	7
Midwest	3	5	0	8	3
West Coast	3	3	0	6	3
Southwest	1	1	0	2	1
Total	**13**	**12**	**2**	**27**	**14**

* One pier/barge vertiport considered for the start-up system would be eliminated in a final system

Figure 6.7.1-2 Estimated Vertiport Requirements

Representative vertiport networks were defined that satisfied projected CTR passenger demand in the four U.S. corridors studied. Figure 6.7.1-2 shows the number and types of vertiports in these representative networks. Overall, 27 vertiports would be required. Based on a review of available facilities and local demand studies, 14 of these vertiports could be located at existing airports. Most vertiports at airports are assumed to be at ground level. Two vertiports were assumed to be located on piers or barges.

A full network of large, sophisticated vertiports will not spring into existence all at once. The start-up system recognizes this fact. Establishing a start-up network will minimize the initial investment while demonstrating how such a network can be achieved. With proper timing and coordination, this will also provide assurance of the availability of infrastructure and enable the manufacturers to make a commitment to build the 40-passenger CTR.

CTR ground infrastructure cost estimates (figure 6.1.1-3) were developed for a start-up system and a mature system. The total cost of both is

	Vertiport Cost	Automobile Parking	ATC/ Navigation	Total Cost
Startup	50	11	6	67
Mature	487	70	42	599
Total	**537**	**81**	**48**	**666**

Figure 6.7.1-3 Estimated CTR Ground Infrastructure Costs for Four U.S. Corridors (in Millions of Dollars)

estimated at $670 million, including $48 million for towers and related ATC and navigation facilities. In addition, the estimates include over $81 million for automobile parking facilities at vertiports. These cost estimates do not include improvements to highway or rail access systems. Costs for noise or environmental mitigation measures, which are site specific and extremely difficult to estimate, are not included. Vertiport development costs are significant, but, by comparison, a single IFR runway with associated lighting and navigation equipment at a major airport can cost $80 to $500 million.

6.7.2 Vertiport Revenues

Revenue can be generated from aeronautical vertiport users based on rent, landing fees, space rentals, or other comparable facility use charges. Other potential sources of revenue include fuel sales, aircraft maintenance, and hanger fees.

AIP grants, with revenues derived from passenger taxes, may be used for vertiport development. The future availability of such funding is uncertain. However, in future legislation, vertiports will probably be treated in a manner similar to airports.

Non-aeronautical revenues come primarily from parking and from concessions, such as restaurants, retail shops, rental cars, wall advertising space, and airport hotels. Vertiport concession revenues are expected to be significantly smaller than those at conventional airports. However, parking fees might be a source of revenue for vertiports, particularly in suburban locations. The availability of these various revenue sources is dependent on the location and character of a particular vertiport.

6.7.3 Vertiport Financing Sources

This section describes a variety of financial alternatives for financing airport improvements, including several traditional methods. In order to obtain funding, it will be crucial to convince the involved entities of the feasibility, viability, and benefits of the vertiport program. Various methods of financing may be used in combination.

- *Federal Airport Assistance*

Under current law, vertiports would be eligible for AIP funding available from the Airport and Airway Trust Fund with revenues derived from user taxes. Federal airport aid programs have been ongoing for the past half century. The continuation of the Airport and Airway Trust Fund user taxes is subject to future Government policy.

Under existing law, vertiports are eligible for formula-driven enplanement funds once they have a sufficient number of annual passengers. AIP funds may support land acquisition or new construction but may not be used for past construction debt.

- *Passenger Facility Charges*

Passenger Facility Charges (PFC) are fees imposed by commercial service airports for each paying airline passenger enplaning at that airport. PFCs are considered local funds, not Federal grants, although FAA approval is required to impose and use the fees collected. To date, the FAA has approved the imposition of PFCs totaling $11.24 billion for current and future projects.

Vertiports would be eligible for PFC funding under the same criteria as airports. In a start-up scenario, a vertiport may not immediately have sufficient passenger service to justify the imposition of a PFC. However, the vertiport could be funded from PFCs imposed at an airport or other facility if it were under sufficient control of a public airport agency with PFC authority.

- *Other Federal Grant Programs*

In addition to AIP grants, there may be grant funds available through other agencies for the infrastructure required to support a vertiport. For example, access roads could be funded through Federal Highway Administration (FHWA) programs. Mass transit systems could be funded through Federal Transit Administration (FTA) programs and the Intermodal Surface Transportation

Efficiency Act (ISTEA) of 1991. However, these programs have historically put a low priority on airport access projects.

- *State and Local Government Programs*

State and local government programs represent another possible source of funding. These funds may be used for aviation-related projects, but may also be designated for infrastructure necessary to the development of a vertiport. Local governments can use tax-exempt financing methods such as bonds or other tax incentives to foster vertiport development, although there is usually competition for available funding.

- *Bonds and Tax Incentives*

Bonds are a form of financing available to both the public and private sector. Public sector bonds are ordinarily tax exempt, while private sector bonds are not. However, the private sector may enter into an arrangement for tax-exempt financing of private ventures under certain conditions. Tax-exempt financing is a common method by which local governments provide financing for airport development. Consequently, vertiports that are publicly owned and for public use would arguably be eligible for tax-exempt financing.

Tax incentives may be another method of enhancing the economic feasibility of this type of project, much like grants, PFCs, or contributed capital that would constitute "equity."

- *Private Grants and Gifts*

Governmental entities may occasionally receive grants or gifts of property from the private sector to construct new infrastructure to be owned by the governmental entity and used for a public purpose. The motivation of the private sector grantor may be to increase its property values or the marketability of its own enterprise. One example would be for a private sector party to contribute to the development of a vertiport because that party owns adjacent land and/or office buildings.

- *Public/Private Partnerships*

Public/private partnerships would probably require the governmental entity to act in an entrepreneurial capacity, rather than in its traditional sovereign capacity. The facilities developed under financing arrangements of this type would still need to be used for a public purpose.

Such a partnership would involve a contribution from each of the organizations involved. The Federal contribution could be management personnel and the funds required for detailed planning of each of the vertiport networks. The contribution from the states, metropolitan governments, and industry could be in the form of labor and the standard AIP state and local matching funds. The development of vertiports in combination with other public facilities (e.g., convention, sports, or shopping centers) could involve partnerships between local governments and private interests.

6.7.4 Vertiport System Financial Analysis

Whatever the revenue source, most large airport projects typically use bond market financing for construction costs. Even for projects that can be fully self-sustaining with landing fee revenues, there is still a need to pay for construction prior to earning those landing fees. For this reason, the financial community will have an interest in the potential viability of vertiports and whether they will generate sufficient income to service their debt. Initially vertiports are likely to be viewed as risky investments by the financial community, because there is no history of vertiport or CTR operation. It may be necessary, therefore, to tie the vertiport to a port or airport operator to provide guarantees on debt service. If, for example, the airports that benefited from CTR congestion mitigation imposed PFCs to pay for vertiports, the financing community could be likely to look more favorably on vertiport financing. For vertiports that are not associated with an existing commercial service airport, initial construction may require public or private loan guarantees to obtain financing from private capital markets.

To repay the capital outlays outlined above and support ongoing operations and maintenance expenses, vertiports need to generate significant amounts of revenue. The primary sources for these

revenues include: (1) CTR operators, (2) landing fees and other charges, and (3) PFCs or AIP allocations derived from user taxes. Whether sufficient revenues might exist to offset anticipated expenses depends on assumptions concerning the availability of Federal airport funding mechanisms.

Figure 6.7.4-1 summarizes various estimates of vertiport finances. Under the present law, vertiports are eligible for funding under AIP/PFC as well as other sources. While some AIP or PFC funding may be available, it is expected that the bulk of the construction funding may have to come from private capital markets and that financial feasibility will have to be demonstrated.

Scenario	Revenues Less Capital and O&M Costs
Existing AIP formula	- $5 million
$3 PFC with no AIP	- $12 million
$3 PFC with 50% AIP allocation	+ $11 million
$4 PFC with no AIP	0
$4 PFC with 50% AIP allocation	+ $23 million

Note: Estimates include landing fees and other operator charges at $125 per flight and vertiport operation and maintenance (O&M) costs at $2.10 per passenger. AIP discretionary funding is not included. Revenues and costs from other activities (e.g., automobile parking, use by other aircraft) are not included.

Figure 6.7.4-1 Estimated Vertiport Finances in Four U.S. Corridors in Year 2010

Figure 6.7.4-2 shows a summary of estimated public/private partnership and CTR infrastructure planning and development costs. This figure includes $9.4 million in partnership and system planning costs, $68 million in start-up infrastructure costs, and $599 million for the planning and development of four vertiport networks.

Year	Cost (millions of dollars)
1996	0.2
1997	0.9
1998	1.3
1999	0.7
2000	1.9
2001	3.8
2002	6.9
2003	8.5
2004	41.2
2005	109.5
2006	121.9
2007	195.3
2008	147.4
2009	28.5
2010	4.1
2011	3.7
Total	**675.8**

Figure 6.7.4-2 Estimated CTR Infrastructure Construction Costs

7.0 Economic and Financial Outlook

- The CTR could be economically viable.
- The CTR could divert approximately 11 percent of air passengers in the four U.S. corridors studied.
- CTR market share would be largest when competing against high-cost air carriers.
- CTR fares would be higher than prevailing air fares but could be offset for some passengers by reduced access time and cost.
- Locating vertiports close to passenger demand centers is critical to CTR economic viability.
- The largest CTR passenger demand sensitivities involve air carrier and CTR fares and travel times, and the siting of vertiports.
- A cooperative effort on the part of manufacturers, operators, government, and local planning authorities is essential to CTR success. No one party can absorb all the risks or overcome all the institutional barriers.
- Worldwide demand forecasts are more uncertain but may be conservative because no estimates were made for several world regions.

7.1 Analytical Approach

A key question that must be answered before civil tiltrotor (CTR) development can move forward is that of economic viability. Can CTRs earn a return on investment that is large enough to allow manufacturers to recover all production and developments costs, plus a reasonable profit? Can operators recover acquisition and operating costs, plus a reasonable profit? Economic viability can be analyzed by looking at the discounted cash flows of CTR development, production, and operation using appropriate discount rates. This chapter summarizes the economic and financial analyses conducted for the CTRDAC. The analyses are covered in greater detail in Volume II of this report prepared by the Civil Tiltrotor Development Advisory Committee (CTRDAC) Economics Subcommittee. A discussion of the various models used in the analysis is contained in section E3.4 of Volume II.

The economic viability of CTR was assessed by performing market analyses for various economic and transportation scenarios involving introduction of scheduled CTR passenger service in the year 2007. Four potential market areas were considered: Northeast, Midwest, West Coast, and Southwest. For each scenario, diversion estimates were made from each of the existing modes (air, auto, and rail) and for business and non-business trip purposes. The air mode was separated into jet and turboprop categories as well as origin-to-destination and transfer market segments.

The market analyses developed estimates for:

- Travel by existing modes in the base year of 1993.
- Travel projections in the years 2010 to 2030.
- Modal characteristics in the future, including travel time, fares, and frequency.
- Diversions to the proposed CTR service.
- Costs of acquiring CTR aircraft and vertiports.
- Costs of operating the CTR system.
- Congestion, energy, and emissions.
- Financial summary measurements (e.g., estimates of revenues and costs in future years).
- Sensitivity analyses of financial forecasts to changes in assumptions.

The main market demand model used a three-step process based on the concept that the introduction of a new mode such as the CTR will result in individuals reconsidering the attributes of each of the modes, and then selecting one that best

meets the purpose of the trip. The decision as to which mode to use is driven by how the individual values time (which varies by trip purpose) and the effect of individual preferences for the available modes that were developed through survey research. Figure 7.1-1 is a schematic drawing of the market share diversion models.

Basic assumptions include that CTR would be regarded by travelers as equal to a turboprop in amenities, comfort, and safety. Travelers were assumed to have a preference for jet travel over both CTR and turboprop. The value of this preference increases with trip distance. At 500 miles the preference is one-third higher than at 200 miles.

A financial model was used to estimate passenger demand, service characteristics, and costs of CTR operations related to specific vertiport pairs. A vertiport cost model was used to estimate vertiport construction and operating costs based on elemental design criteria for a set of generalized vertiport layouts that might be located in city centers and suburban locations. Finally, an energy and emissions model was used to measure the impact of these factors resulting from changes in modal demand and access/egress travel times, modal energy intensities, and emission rates.

The overall benefit-cost model was comprised of four cash flow modules, including the National Aeronautics and Space Administration (NASA) and the Federal Aviation Administration (FAA) research and development, manufacturing, operations, and delay plus environmental effects. The research and development cash flow is assumed to begin in 1995 and spans 8 years with total expenditures of approximately $600 million. A manufacturer cash flow model assumed that development costs begin in 2003 and extend for 4 to 5 years. The model also assumed that aircraft deliveries would begin in 2007 and continue for 18 years. Both aircraft development and production costs would be fully funded by manufacturers.

An operations cash flow was developed from the demand analysis that provided activity projections for a base "steady state" year. For the Northeast and Midwest corridors, operations were estimated to begin in 2007, coinciding with the first CTR deliveries, and to build up to the "steady state" year projections by 2011. In the West Coast and Southwest corridors, operations were assumed to begin in 2008 and 2009 respectively and build up to the base year estimates by 2012. In all cases, the scaling of the demand projections was assumed to affect operator revenues in direct proportion to revenue passenger-miles (RPM). Operator costs were broken into three categories: aircraft ownership costs, other fixed costs, and variable costs.

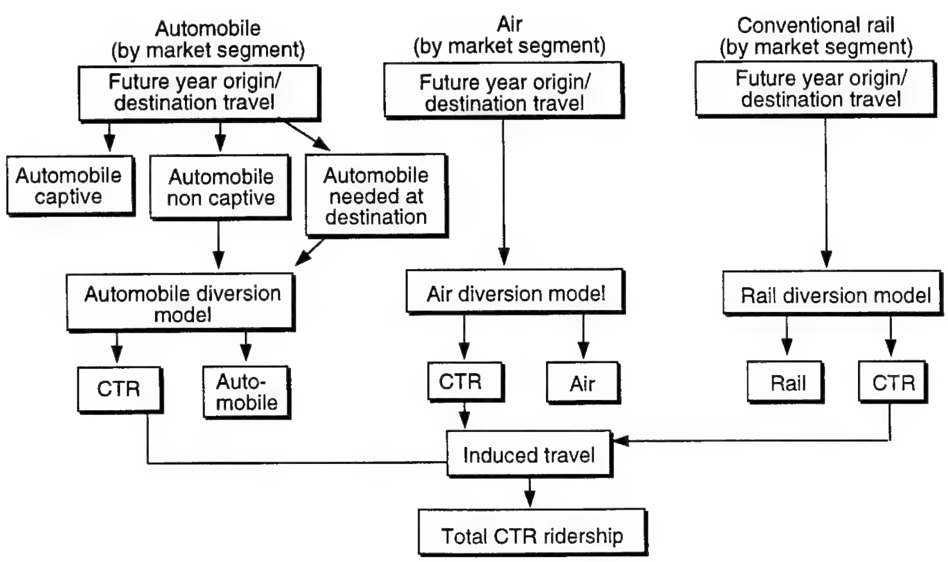


Figure 7.1-1. Market Share Diversion Model

Finally, the delay reduction, energy, and emissions cash flows were expanded in a similar fashion from a base year analysis using RPMs as the relevant activity measure.

7.2 Assumptions

Calculations were carried out in constant 1994 dollars, using the real discount rate of 7 percent recommended by the Office of Management and Budget (OMB). The mode choice analysis assumes a mature CTR system after the market introduction phase and covers the period 2010 to 2030. However, the discounted cash flow analysis described above explicitly considers a start-up phase of operations beginning in 2007.

The analysis assumes the CTR2000 design, with seats for 40 passengers and a normal cruise speed of 360 miles per hour. Three types of CTR service were examined: urban/suburban vertiport to urban/suburban vertiport; regional airports within 500 nautical miles of urban/suburban vertiports (feeder service); and CTR service to air transfer passengers through collocated vertiports at congested hub airports (figure 3.1-1).

Vertiports were assumed to exist in major city centers, surrounding suburban locations, and congested hub airports in major cities with one or more other vertiports. CTR service to uncongested regional airports was assumed to use conventional airport facilities. The number of vertiports in a major city was set to meet the projected travel demand. The first vertiport was assumed to be located in or near the city center. This siting produces the largest advantages for CTR in access/egress travel time and cost. Access/egress times vary by city size, the level of highway congestion, and the number of airports and vertiports.

Conventional airfares were assumed to remain at about current levels in real terms in future years. Adjustments to 1992 airfares were made to account for recent fare fluctuations in the Northeast and some Midwest markets. Additional factors that might either reduce future airfares (e.g., the spread of low-cost carriers) or increase fares (e.g., higher aviation fuel, aircraft or airport costs) were examined as part of sensitivity analyses. Business airfares were assumed to be higher than pleasure fares due to more limited use of discount tickets.

CTR fares were assumed to be set at levels sufficient for CTR operators to match operating costs plus yield a 10 percent return in each market served. CTR fares were assumed to include the 10 percent ticket tax.

Changes in future fixed-wing air delays at congested airports were analyzed in sensitivity analyses. The base case assumes that aviation line-haul travel times remain at current levels. The FAA projects that increases in the number of conventional air operations at many airports will likely lead to higher air system delays in the next decade. However, long-term delay forecasting is quite uncertain. Certain developments could reduce aviation delays below expectations. These include the introduction of new technology (e.g., the use of the Global Positioning System (GPS) and Automatic Dependent Surveillance (ADS) for air traffic control (ATC)), added runway capacity, or use of reliever airports, changes in airline hubbing practices, increased aircraft sizes and higher average load factors, and diversions to high-speed rail and CTR . On the other hand, a growing economy or a reduction in airline ticket prices could increase air travel and create significant additional delay.

It was also assumed that:

- The baseline CTR purchase price would be $18.5 million with a distance-based operating cost function for fuel, air crew, and maintenance and other estimates for landing, ground property, equipment fees, and administration.
- CTR operating costs would be based on evenly-spaced flight schedules over 16-hour days, six days per week with an average annual utilization of 2,300 hours per aircraft.
- CTRs would follow existing turboprop routes between cities, but fly directly to vertiports without significant delays once in the terminal area. All flying would be point-to-point with no multiple stops within the same city.

- CTR line-haul travel times would be calculated from typical flight profiles, but CTR taxi-in and taxi-out times would be shorter than for fixed-wing aircraft.

- A demand model would be used to project future potential air traffic in markets of less than 500 miles.

- The share of business air travel would remain the same as today, averaging about 48 percent nationally and declining with distance traveled.

- Aircraft sizes and load factors would increase in future years in line with other FAA forecasts and the CTR load factor would average 60 percent. This is lower than the national average but consistent with load factors achieved in markets of less than 500 miles.

- Video conferencing and other communications technologies would not have a major impact on air travel.

- Vertiport sizes and costs would be set to match forecast CTR demand with operation and maintenance costs similar to those of small airports, or about $2.10 per passenger.

7.3 Economic Viability of Potential CTR Corridors

7.3.1 Introduction

The analysis of the economic viability of CTR found that CTR service could attract a sizable ridership in a number of domestic markets if introduced in the first or second decade of the next century. CTR service is more likely to be financially viable in the Northeast and some Midwest markets where prevailing airfares are generally higher than in the West Coast and Southwest corridors.

The level of CTR passenger demand will depend on its relative advantage (or disadvantage) over conventional air travel and other existing modes in overall travel time and cost. Total CTR travel time, including line-haul, access/egress and terminal times, is significantly lower than turboprop travel times and is lower than jet travel times in most markets, except those that involve very long trips. Some examples of travel time components are shown in figure 7.3.1-1.

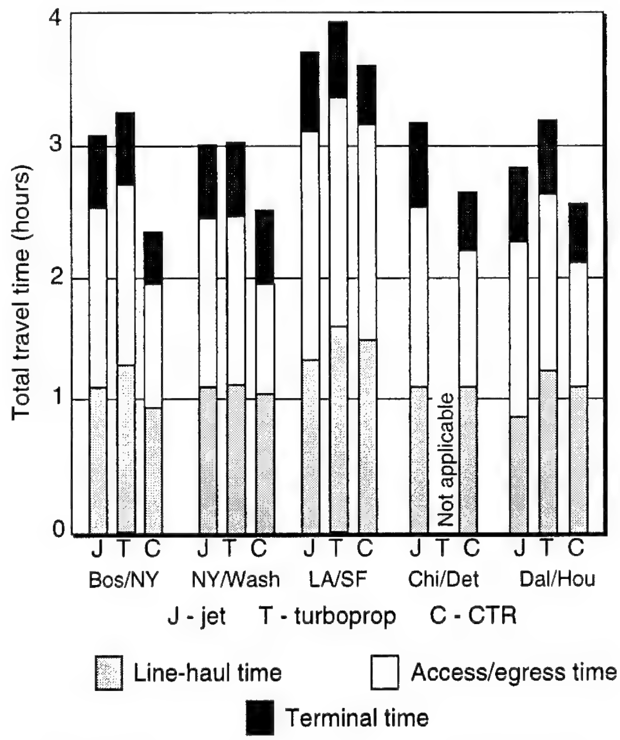


Figure 7.3.1-1 Jet, Turboprop, and CTR Total Travel Times in Key City Pairs

The anticipated CTR cruise speed of the 40-passenger CTR exceeds the cruise speed of most turboprop aircraft, although it is lower than jet aircraft. For particular city pairs, CTR distances flown may also be shorter than that of jets or turboprop aircraft due to more direct CTR routings in terminal areas.

It is assumed that CTRs will not be subject to runway-related terminal area delays that lengthen conventional air travel in many congested metropolitan areas. Because of its vertical flight capability, analysis has shown that CTRs could proceed more directly to downtown and on-airport vertiports than conventional aircraft can approach airports.[1]

[1] Civil Tiltrotor Terminal Area Route Development Study, DOT/FAA/ASD-410-95-002, prepared by CSSI, Incorporated and FAA Operations Research Service, April 1995.

The CTR is expected to attract substantial demand because total travel time and costs will be less than for other modes for many passengers. For most potential markets, CTR airfares are expected to be higher than for conventional aircraft to cover the higher CTR acquisition and operating costs. Access/egress expenses are projected to be slightly smaller for CTR passengers because it is assumed that vertiports will be located closer to trip origination and destination points than existing airports.

7.3.2 Diversion Rates

The combination of travel time and passenger cost factors results in a pattern of CTR diversions from conventional air that varies from market to market (figure 7.3.2-1). The most important determinants of diversion are the suitability of vertiport locations and the CTR fare premium over competitive conventional air service. Favorable CTR diversion rates can be realized in city pairs where existing conventional airfares are high, such as the Northeast and some Midwest markets. In the West Coast and Southwest corridors, where airfares are traditionally low, diversions would be much lower.

Corridor	Percent Diverted From Air	Typical Fare Premium (percentage)	Typical Fare Premium for Major Markets (dollars)
Northeast	20	45	51
Midwest	12	15 to 125	69
West Coast	4	135	115
Southwest	6	130	86
Overall	**11**		

Figure 7.3.2-1 CTR Diversion Rates and Fare Premiums for Vertiport-to-Vertiport and Feeder Routes in 2010

Figure 7.3.2-2 shows the 1992 average fares per mile of the three largest passenger volume markets in each subject corridor. It is clear that there are major differences in fare levels among these corridors and among individual markets, especially in the Midwest.

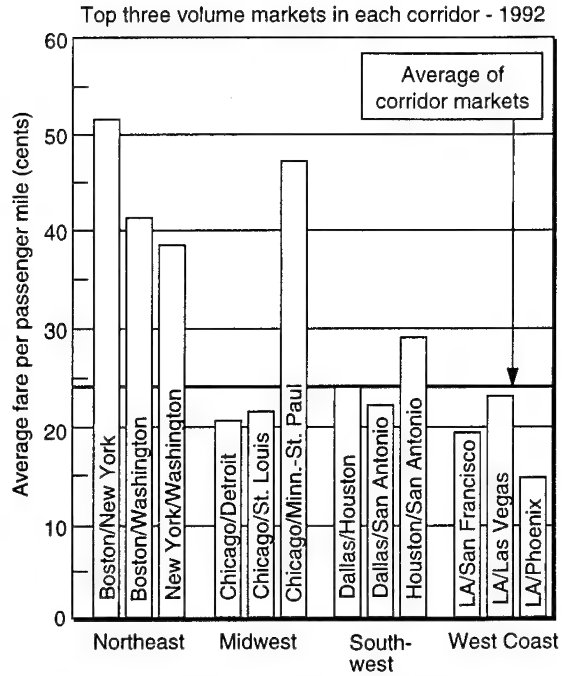


Figure 7.3.2-2. Typical Air Carrier Fares per Mile

The opportunity to site vertiports in downtown and other favorable suburban locations is also an important determinant of CTR viability. As noted below in the sensitivity analyses, if less advantageous vertiport sites must be used, CTR demand might drop by as much as one-third.

Diversions to CTR service are higher for business travelers because they place a higher value on travel time and will pay more in out-of-pocket travel costs to save time. Diversion rates are also higher for former turboprop passengers because CTR has a time advantage over this aircraft type. In addition, the model assumes a passenger preference toward jets, but no absolute preference between turboprops and CTRs.[2]

In general, diversion rates for air origin-to-destination (O/D) travel are higher than for connecting or transfer travel. This is primarily due to lower values of time for air-transfer passengers. However, there are also smaller access time advantages since travellers would use a vertiport at only

[2] In future research, it may be productive to try to determine how the turboprop mode preference penalty varies with aircraft size.

one end of the trip. It is also assumed that CTR passengers will spend more time transferring between terminals.

The expected number of passengers diverted to CTR service depends on the base level of existing air travel as shown in figure 7.3.2-3, as well as the projected CTR diversion rate. City pairs with significant amounts of conventional air travel will be more likely to support CTR service because they are more likely to justify a minimum level of CTR flights.

Corridor	O/D Traffic	Feeder Traffic	Transfer Traffic
Northeast	5.4	10.8	6.6
Midwest	7.2	8.4	21.2
West Coast	18.4	5.9	5.7
Southwest	3.2	6.7	6.9

NOTES: • Annual passengers in millions; one-way trips
• Includes only cities expected to have vertiports

Figure 7.3.2-3 Existing Air Passengers by Corridor in 1992

7.3.3 CTR Enplanement Trip Projections

The following estimates of future CTR travel are based on forecasts of conventional air travel that are consistent with FAA long-term forecasts, assuming no major changes in airfares from 1994 levels. CTR travel estimates have been broken into three categories:

- *Vertiport-to-Vertiport Travel*

Origin-to-destination travel between major metropolitan areas served by one or more downtown and suburban vertiport locations (figure 7.3.3-1).

Northeast	Midwest	West Coast	Southwest
Boston New York Washington Philadelphia	Chicago Detroit Cleveland Pittsburgh Cincinnati Minneapolis	San Diego Los Angeles San Francisco Las Vegas	Dallas Houston

Figure 7.3.3-1 Major Metropolitan Areas

- *Feeder Travel*

Between vertiports in major metropolitan areas and uncongested airports within 500 miles. Special CTR facilities are not assumed at the feeder airport end of the flight. Inclusion of vertiports at feeder airports might increase diversion rates a few percentage points.

- *Transfer Passenger Service*

Connecting passengers diverted from longer trips where one leg is either a vertiport-to-airport segment or a feeder segment. It is assumed that these types of diversions could only occur where a vertiport is collocated at a metropolitan-area airport.

CTR travel to feeder airports is an important component in the Northeast and Midwest, and diverted transfer travel contributes substantially to overall CTR ridership in the Midwest. However, a substantial portion of connecting air traffic is a by-product of current hub-based airline flight patterns. Because hubbing practices change over time and the future sites of airline hubs are uncertain, the estimates of CTR travel diverted from connecting air passenger traffic is much less certain than estimates made regarding O/D air travelers. For this reason, transfer passengers were not included in the economic analysis of CTR viability. Figure 7.3.3-2 shows total enplanement trip projections. Figure 7.3.3-3 shows a summary of air trips by corridor in the base year of 2010 with and without CTR.

7.3.4 CTR Passenger Profile

Most CTR passengers are time-sensitive business travelers, but even with premium fares, CTR service is able to attract a reasonable number of non-business (pleasure) travelers. On O/D itineraries, about 35 percent of CTR travel is estimated to be for non-business purposes. The percentage of non-business travel is projected to be substantially higher on trips involving a transfer between conventional air and CTR.

Nearly all CTR passengers are former air travelers. Diversions from auto and rail modes are insignificant in most markets. CTR service is

Corridor	Vertiport-to-Vertiport	Feeder	Transfer	Total
Northeast	3.4	2.5	1.0	6.9
Midwest	0.7	2.8	3.5	7.0
West Coast	1.3	0.2	0.3	1.8
Southwest	0.3	0.0	0.1	0.4
Total	**5.7**	**5.5**	**4.9**	**16.1**

Figure 7.3.3-2 Annual CTR Enplanement Trip Projections in 2010 (In Millions)

Corridor	Without CTR	With CTR **		
	Conventional Air	CTR *	Conventional Air	Total
Northeast	27.1	5.7	21.8	27.4
Midwest	25.3	3.3	22.2	25.5
West Coast	40.4	1.5	38.9	40.4
Southwest	4.6	0.3	4.3	4.6
Total	**97.4**	**10.8**	**87.2**	**98.0**

* Air diversions only; an extra 0.4 million CTR trips would be diverted from auto and rail

** Vertiport-to-vertiport and feeder services; transfer not included

Figure 7.3.3-3 Estimates of 2010 Air Travel (Origin-Destination) For Travel Suitable for CTR Services, With and Without CTR Services Available (Millions of Trips)

projected to attain modest shares of auto and rail passengers only when CTR fares are assumed to be relatively low. This finding is consistent with the expectation that passengers who value their time most highly have already chosen conventional air over the surface modes.

Although CTR competes more successfully with turboprop operations, most CTR passengers are former jet passengers. This is because a very high percentage of existing air passengers in markets likely to be served by CTRs currently use available jet services.

Figure 7.3.4-1 shows that CTR travel will grow moderately once established. Additional diversions to CTR will occur because population growth-

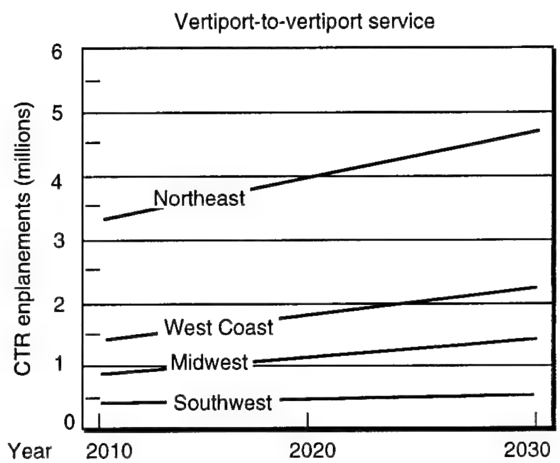


Figure 7.3.4-1 Annual CTR Enplanements by Corridor

based volume increases will lead to increased CTR flight frequency and a potential requirement for additional metropolitan area vertiports. Increasing flight frequency and adding additional vertiports will cause a shift in additional passengers to CTR. The overall growth in CTR patronage between 2010 and 2030 is estimated to be about 45 percent, or approximately 1.9 percent per year.

7.3.5 CTR Aircraft and Vertiport Requirements

The number of CTR aircraft required to meet projected passenger demand (figure 7.3.5-1) is estimated directly from assumptions about average load factors and aircraft utilization (flight hours per year), as well as estimates of CTR travel times and passengers carried.

Corridor	Vertiport-to-Vertiport	Feeder	Transfer	Total
Northeast	67	60	22	149
Midwest	18	47	64	129
West Coast	35	2	4	41
Southwest	6	0	1	7
Total	**126**	**109**	**91**	**326**

Figure 7.3.5-1 Estimated CTR Aircraft Requirements in Four Major Corridors in 2010

The number of CTR aircraft required in 2010 for the four market areas investigated ranges from 126 for vertiport-to-vertiport travel to 326 if feeder and transfer passengers are included. These projected CTR aircraft requirements are consistent with the vehicle units suggested by industry for calculating CTR aircraft production costs, if some level of exports of CTR vehicles is assumed.

Requirements for CTR aircraft are expected to increase over time as passenger demand for CTR services expands. Figure 7.3.5-2 shows the estimated CTR aircraft requirements in the four U.S. corridors studied increase from 326 units in 2010 to 454 units in 2030.

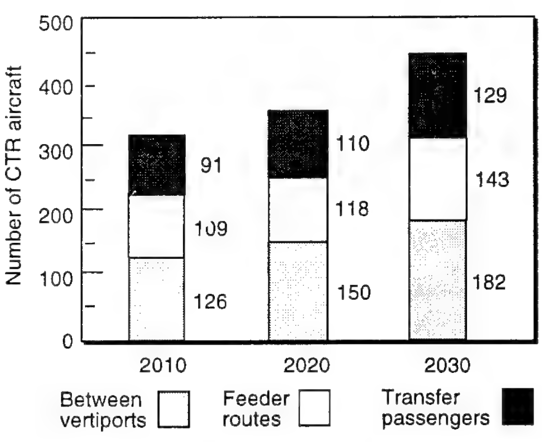


Figure 7.3.5-2 Estimated CTR Aircraft Requirements for Four U.S. Corridors, 2010 to 2030

7.3.6 CTR Fare Premiums

The analysis assumes that, to be economically viable, CTR operators will need to set fares at levels high enough to completely cover baseline CTR operating costs, and provide the operator with a sufficient return on investment to defray the cost of capital.[3] CTR operating costs were estimated using national averages for many indirect cost categories. In market areas with significant low-fare carrier presence, higher CTR fares would lead to high CTR fare premiums and, as a consequence, relatively low diversion rates from existing air services. Conversely, in markets characterized by high conventional airfares, CTR fare premiums are low and CTR market shares are projected to be reasonably high. It should be noted that the observed fares for conventional air may not cover all operating costs and provide an adequate return for the operator to replenish capital.

Figure 7.3.6-1 shows CTR fare premiums as a percentage of conventional airfares for a sample of typical city-pair markets in each analysis corridor. The highest CTR fare premiums (about 135 percent) occur in the West Coast and Southwest corridors and a few Midwest markets, which are dominated by Southwest Airlines. In the Northeast and some Midwest markets, required CTR fare

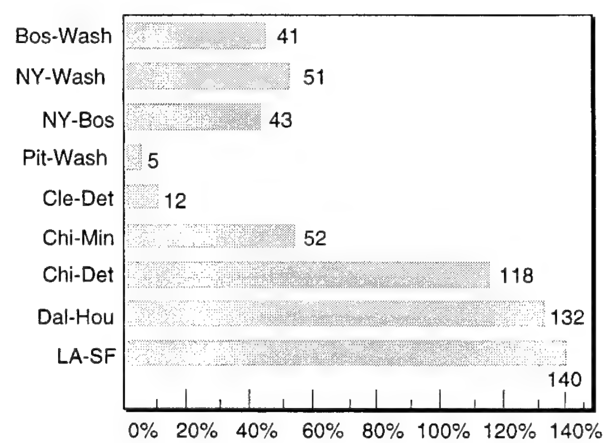


Figure 7.3.6-1 Estimated CTR Fare Premium in Key City Pairs

[3] As noted above, the mode choice model estimates diversions to CTR based on the full price of travel, including airfares, access time and costs, value of travel time, and schedule availability.

premiums are lower (about 45 percent), while in other Midwest markets, break-even CTR fares could be set roughly equal to existing airfares.

CTR diversion rates from conventional jet air service are higher (e.g., 15 percent to 40 percent) in high-fare conventional airfare markets. They are lower (e.g., 10 percent or less) in low-fare markets. Figure 7.3.6-2 illustrates this trend in business travel markets, and also shows that CTR diversion rates fall as the distance between city pairs increases.

CTR dollar fare premiums on an absolute basis are shown in figure 7.3.6-3. The differences between CTR fares and average conventional airfares typically range from under \$10 in the Northeast/Midwest to over \$100 in a few low-fare markets. The average absolute fare differences, while significant, are generally less than the differences between quoted full fares and discount fares.

The difference in total travel costs between the CTR and conventional air travelers is reduced somewhat by savings that CTR travelers often will receive in access/egress costs. Many travelers will be closer to vertiports than to existing airports. This savings can be significant in individual cases, but averages only a few dollars per trip because many air access trips have a high fixed component (e.g., parking fees) which is paid no matter how far a traveler is from the air terminal. Passengers who divert to CTRs will be willing to pay these higher out-of-pocket costs because they are more than offset by the value of travel time saved.[4]

7.3.7 CTR Ridership Sensitivity Analysis

An analysis was performed to measure the sensitivity of CTR ridership forecasts to variations in key assumptions. A summary of the results of this analysis are shown in figure 7.3.7-1. The most important variables affecting CTR ridership are the level of conventional air fares, CTR costs/fares relative to conventional air fares, and the proximity of vertiports to demand centers. For example, if conventional airfares rise by 15 percent, CTR rid-

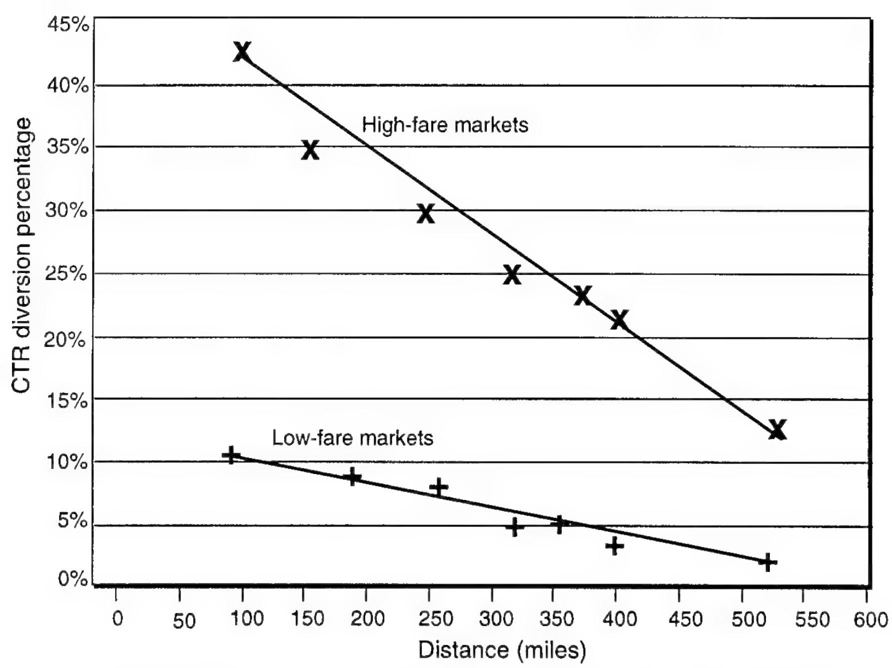


Figure 7.3.6-2. CTR Diversion Percentage Versus Distance for Business Market Segment (Jet Service)

[4] The diversion model assumes that access/egress costs are represented by automobile costs and that parking costs are included. The model assumes no difference between parking costs at airports and vertiports. Because many business travelers use taxis, limousines or other commercial access modes, the assumption that access/egress costs are equivalent to automobile costs may understate access cost savings for CTR business travelers.

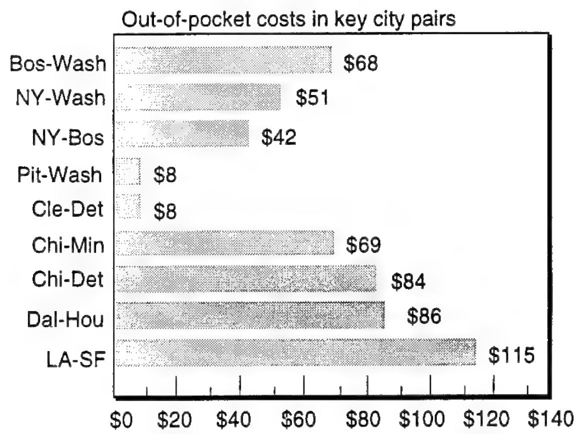


Figure 7.3.6-3. Estimated Fare Differences Between CTR and Air

Variable	Change in Assumptions	Change in CTR Ridership
Conventional airfares	+15%	+17%
	-15%	-17%
Conventional air delay per operation	+20%	+9%
CTR fares	-10%	+45% to +80%
	-20%	+95% to +160%
	+20%	-45% to -70%
CTR initial price	+10%	-10%
	-10%	+10%
CTR line-haul travel time	+10%	-7%
	-10%	+14%
CTR utilization	-10%	-11%
	+10%	+9%
CTR load factor	-10%	-19%
	+10%	+14%
Vertiport locations	Less favorable	-31% to -33%
	One per city	-17% to -25%

Figure 7.3.7-1 Sensitivity of CTR Ridership to Variation in Key Assumptions

ership would rise by 17 percent. If conventional airfares fall by 15 percent, CTR ridership would fall by 17 percent.

A 20 percent reduction in CTR fares would result in an increase in ridership of 95 to 160 percent. A comparable increase in CTR fares would result in a reduction in ridership of 45 to 70 percent. If all vertiports in the network were located in unfavorable locations, ridership would decrease by as much as 33 percent.

7.4 Manufacturing Economics

7.4.1 Key Factors Affecting Launch Decision

A manufacturer will only launch a CTR program when it believes it can sell enough units over a short enough period of time at a price sufficient to recover investment and manufacturing costs while earning a return on the capital employed. A manufacturer also will need firm orders from customer airlines to launch a CTR program. In addition to resolution of infrastructure issues and obtaining airline operator interest in CTRs, the key quantitative factors affecting a launch decision by a CTR manufacturer include:

- Development and tooling costs.
- Rate of learning on production costs.
- Number of units sold.
- Time over which units are sold.
- Prices realized (based on value to airline).
- Cost of money (reflecting risk and cost of capital).

Typically, transport aircraft manufacturers require 400 or more unit sales for a new aircraft launch program to break even.

The cost to build CTRs can be estimated within reasonable bounds based on prior experience in a format that is generally accepted industry-wide. The estimation process requires dividing production costs into two major categories, nonrecurring and recurring. Nonrecurring costs are associated with designing the vehicle and preparing for production, including design and construction of tooling and facilities, production of test articles, and general testing and certification. Recurring costs occur with each vehicle produced, including engines, airframes, rotors and drive systems, interiors, avionics, etc. Recurring costs are influenced by production rate and the learning curve effect. Higher production rates allow more favorable in-

puts on purchased items and allow the allocation of fixed development and tooling costs over more units. The learning curve refers to the phenomenon whereby production workers and production processes *learn* to be more efficient in producing subsequent units, lowering the cost of production.

Of these two influences, the learning curve is most pronounced. Historically, successful commercial airliner manufacturing programs have experienced learning curves in the 80 to 90 percent range. An 85 percent learning curve means that every time the quantity produced doubles, the unit cost is reduced by a factor of 0.85. On very large production runs, the later phases normally experience a lesser rate of learning. Conversely, lower than expected production rates also can reduce the learning curve benefits as personnel turnover and less efficient tool use occurs.

A CTR launch decision is not purely technical or economic. Actions (or non-actions) by potential operators and the Government will be principal considerations as a manufacturer decides when and if a launch decision is made for a CTR program. An overview of how manufacturers view those external risks together with prospects for resolving or reducing those risks is discussed in Chapter 12 of this report. The remainder of this chapter focuses on those economic factors considered by a manufacturer in its decision to launch a CTR program.

7.4.2 Worldwide CTR Market Demand

Several sources were used to develop the worldwide CTR market demand projections for this study. As noted previously, this report provides an up-to-date assessment of the likely CTR market in four high-density travel corridors in the U.S. These estimates were used in combination with prior studies, such as the two phases of the NASA/FAA civil tiltrotor studies that considered worldwide market demand. Phase I of that study identified several market segments, the largest of which was for a 36- to 45-passenger aircraft in regional air transportation. Phase II of the NASA/FAA effort focused on the economic performance of, and potential world market demand for, a 40-passenger tiltrotor.

As noted above, the demand analysis covered four U.S. corridors and three categories of potential air travel diversion (vertiport-to-vertiport, feeder, and transfer). To develop a worldwide estimate of CTR requirements, the vertiport-to-vertiport and feeder results were added together to establish a "lower bound" forecast for the four U.S. corridors. Adding the transfer requirements that represent a more speculative opportunity for CTR diversion creates an "upper bound" level. Using the relation between the four corridor values and the earlier NASA/FAA phase II estimates for the same corridors, values for the North American regions not included in the demand model (Hawaii, Gulf Coast, Southeast and Florida, Canada, etc.) were scaled to the demand model projections.

CTR demand potential in foreign countries relied on industry marketing studies started after the NASA/FAA phase II study. Because of significantly different economic and social climates, as well as variations in analysis methods and assumptions, there is substantially more uncertainty about the levels of projected CTR demand outside the U.S. In 1992, a detailed analysis of the European market for a 40-passenger tiltrotor was completed by U.S. and European industry.[5] Eurostudy evaluated the competition from emerging European high-speed rail system and determined the CTR market capture. Eurostudy projected a year 2010 demand of approximately 130 to 1,200 CTRs dependent on fare levels. A demand for 300 units was identified as the baseline case.

A major Japanese market study is now being conducted by industry, but results will not be complete until later this year. Preliminary information indicates a market for 300 to 400 aircraft. The NASA/FAA Phase II estimate for Oceania was reduced by the ratio found in the U.S. corridors. Other regions (i.e. South America, Africa,

[5] Alenia/Bell/British Aerospace/Dornier/Boeing, Eurostudy - A Market Analysis of Commercial Tiltrotor In Europe, December 1992

Asia, and the Middle East) have not been included in the market demand projections. To the extent these regions have CTR requirements, they would be in addition to those identified below.

The market projections also include 75 to 150 aircraft for other missions such as package express, as identified in discussions with that rapidly growing industry during the NASA/FAA Phase I study. Figure 7.4.2-1 shows the worldwide CTR market projection for a 40-passenger aircraft. The projections range from 1,160 to 1,600 aircraft in the year 2010. These projections exceed by a large margin the minimum number required by manufacturers to earn an economic rate of return. Minimum manufacturer CTR production levels are discussed later in this chapter.

Market Region	Forecast Range
Four major U.S. corridor markets (note 1)	235 to 325
Other North American corridor markets (note 1)	150 to 200
Europe	300 to 400
Japan	300 to 400
Oceania	100 to 125
Total passenger CTRs	1,085 to 1,450
Other applications (note 2)	75 to 150
Total	**1,160 to 1,600**

Note 1: Vertiport-to-vertiport, plus feeder, plus transfer markets. Transfer market included in top end of the range

Note 2: Other worldwide applications for 40-seat aircraft include package express, corporate, search and rescue.

Figure 7.4.2-1 Worldwide Demand Forecast for 40-Seat CTR in 2010

7.4.3 Development Timing Issues

The timing of development for a CTR program launch depends on a number of factors. Some of these, such as the development of vertiports, are beyond the control of the manufacturers. Additional research is required. The timing and results of this research, as well as how it is financed, also affect the likely economic viability of a CTR production program and the decision of a manufacturer to launch a program. In addition, two U.S. manufacturers believe that a smaller commercial tiltrotor (on the order of nine seats) for the utility market (industrial, air taxi, corporate, and other uses) could be launched prior to the development of a 40-passenger vehicle for scheduled passenger transportation. As such, there is uncertainty about the actual timing of CTR development. The discussion below considers the earliest time frame in which a U.S. manufacturer could launch a commercial, 40-passenger tiltrotor program.

Given the time needed for additional research and assuming a 4- to 5-year development period after program launch, it is assumed that the earliest delivery of a 40-passenger CTR would occur in the year 2007 or later. In the discounted cash flow analysis below and in the assessment of private and social benefits presented in Chapter 10, it is assumed that first deliveries take place in 2007. Using the production rate assumptions listed below, it is assumed that sufficient vehicles could be delivered to the U.S. market to meet the projected demand in the vertiport-to-vertiport and feeder markets no later than the year 2012 for the four U.S. corridors studied. It is assumed that additional production would be exported and sold overseas.

7.4.4 CTR Manufacturer Cash Flow Analysis

A discounted cash flow analysis model was developed to determine the number of CTRs required to produce a positive net present value (NPV) for the production program. The analysis shows that, at a selling price of $18.5 million per CTR (1994 dollars), a full production rate of seven CTRs per month and assuming a real discount rate of 12 percent, 506 units would have to be sold within 10 years from go-ahead (41 quarters) for the program to have a positive NPV. This number is well below the worldwide market projection. If production exceeds 506 units over the time period shown, the program return will be larger than 12 percent in real terms.

The cash flow analysis is based on a nonrecurring development cost of $1.2 billion. This is based on industry estimates that reflect recent actions to reduce development times and costs and assumes that a research program precedes program launch. The sensitivity of this assumption is tested below.

The results shown in figure 7.4.4-1 reflect net after-tax expenditures and account for the time value of money. The nonrecurring research and development costs are incurred not all at once, but over a span of four years. For this reason, the present value of these expenditures is less than the nominal outlay.

The cash flow analysis model assumes the time value of money is treated in a consistent way by finding the set of production costs over time that will yield a desired rate of return. This eliminates any dependence on an "average cost" at some level of production (e.g. 500 units).

The analysis also uses a two-stage learning curve in order to draw a distinction between aircraft production and delivery schedules before and after full rate production begins. Early aircraft are used as test aircraft, and these are eventually sold after some refurbishment. Refurbishment costs, however, are not considered in this analysis. The effect of this exclusion is judged to be insignificant relative to other uncertainties.

A sensitivity analysis was performed that examined a scenario where Government research

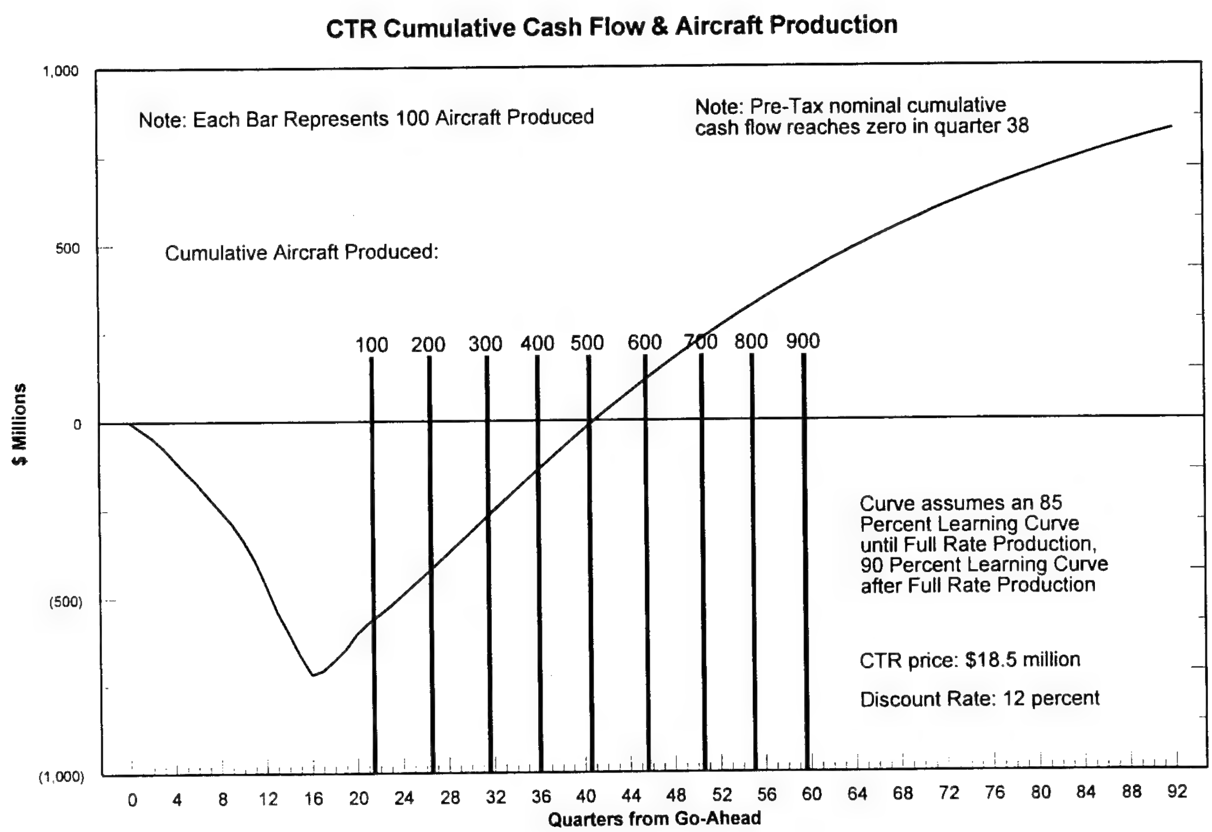


Figure 8.4.4-1 CTR Cumulative Cash Flow and Aircraft Production

funding was not provided. This increased the manufacturer-funded development costs from $1.2 billion over 4 years to $1.8 billion over 8 years. At a selling price of $18.5 million and a production quantity of 506 units, the real rate of return is reduced to about 11 percent. A 12 percent rate of return cannot be attained given the assumed production horizon if the manufacturer bears the cost of assumed Government research and development (R&D) funding. Similar results would occur if nonrecurring development costs were $1.8 billion with Government-financed research and development.

7.5 Operator Economics

CTR operating costs will be higher than typical aircraft because of the vertical flight capability and relatively small size in terms of passenger capacity. However, the inherent advantage of the CTR is not low cost but the accessibility to the ultimate origins and destinations of passengers and cargo. In addition, because of the smaller size of CTRs compared to jet aircraft, more frequent operations may be possible. This subsection discusses CTR costs and compares them to typical airline costs, presents the results of the operator cash flow analysis, and discusses the airline perspective on CTR.

7.5.1 CTR Operating and Capital Costs

Overall CTR costs per passenger trip were estimated to average $113 or $0.29 per available seat-mile (ASM) in the Southwest; $115 or $0.29 per ASM in the Northeast; $125 or $0.27 per ASM in the Midwest; and $135 or $0.25 per ASM on the West Coast. These costs are expected to be somewhat higher than for most conventional, short-haul airlines (figure 7.5.1-1). Because aircraft operating costs decline both with increased stage length and aircraft size, the carriers shown in the lower portion of the figure have much lower seat-mile costs than projected for CTR.

CTR fares in each city-pair market are set to match total operating and annualized capital costs for an autonomous CTR operation and include a margin for a profit. Figure 7.5.1-2 shows an example of a typical CTR cost breakdown. Together, these cost categories comprise all of the costs that a CTR airline would reasonably face, including administrative charges.

Airline	Cost Per Available Seat-Mile (ASM) ($0.01) *	Average Stage Length (miles)
Small-aircraft, short-haul airlines		
USAir Shuttle	24.3	202
Aloha	21.7	132
Horizon	21.1	170
Mesa (group)	20.2	182
Air Wisconsin	19.3	139
Atlantic Coast	18.5	143
Comair	15.6	152
Atlantic Southeast	13.9	238
Other airlines		
USAir	11.5	537
Midwest Express	11.4	683
Northwest	9.5	850
Alaska Air	9.2	692
TransWorld	9.2	846
American	9.0	1033
United	9.0	1061
Continental	8.2	710
Hawaiian	8.0	291
Reno	7.9	447
Kiwi	7.6	847
Southwest	7.2	388
America West	7.1	676

* Not adjusted for stage length
SOURCE: FAA Quarterly Industry Report, 2/95

Figure 7.5.1-1 Airline Operating Costs Per Available Seat-Mile, Fiscal Year 1994

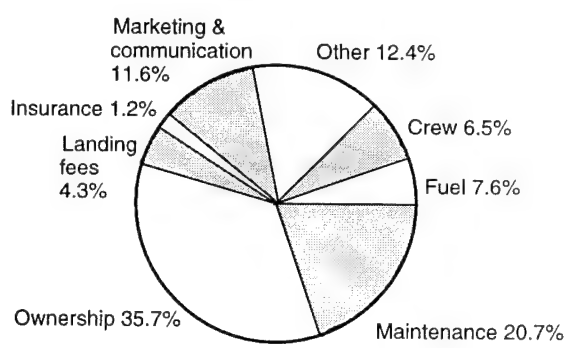


Figure 7.5.1-2. Northeast Corridor CTR Costs Base Case - 2010

Although some CTR cost reductions may be feasible, it is not likely that overall costs could be reduced below conventional airline costs, even if efficiencies similar to low-cost airlines were duplicated in CTR operations. The reason that estimated CTR costs are higher than reported costs for conventional air carriers is that it costs more to acquire and operate aircraft with vertical flight capability. In addition, aircraft passenger mile costs decline as aircraft size increases. Because the analysis assumes a relatively small aircraft (in airline terms) of 40 seats, CTR seat-mile costs are high.

7.5.2 Operator Cash Flow

A discounted cash flow analysis of CTR operations was performed. This was based on the fares, costs, and number of passengers identified above. It covers CTR operations in the four U.S. corridors over the years 2007 to 2025. Figure 7.5.2-1 summarizes cash revenues and expenditures in 1994 dollars for CTR operations in the four U.S. corridors. These include all investment and operating costs as well as taxes. In addition, the cash flow in figure 7.5.2-1 also reflects a terminal value because it is assumed that operations end in 2025 with the disposal of the CTRs. Figure 7.5.2-2 shows the annual cash flows for each year in this period across the four U.S. corridors. Early year negative cash flows must be financed, but these are more than offset by positive cash flows in later years.

Under these assumptions, the operator after-tax internal rate of return (IRR) and NPV at 10 percent for each corridor are shown in figure 7.5.2-3. Across all corridors, the overall rate of return is approximately 11 percent.

Corridor	Revenues	Ownership Costs	Fixed Operating Costs	Variable Operating Costs	Taxes	Net Cash Flow
Northeast	19,200	(7,200)	(500)	(9,600)	(650)	1,250
Midwest	11,000	(4,000)	(160)	(5,800)	(350)	690
Southwest	750	(300)	(30)	(340)	(30)	50
West Coast	4,900	(1,900)	(240)	(2,360)	(150)	250

Figure 7.5.2-1 CTR Operator Cash Flow by Corridor For 20 Years (Millions of 1994 Dollars)

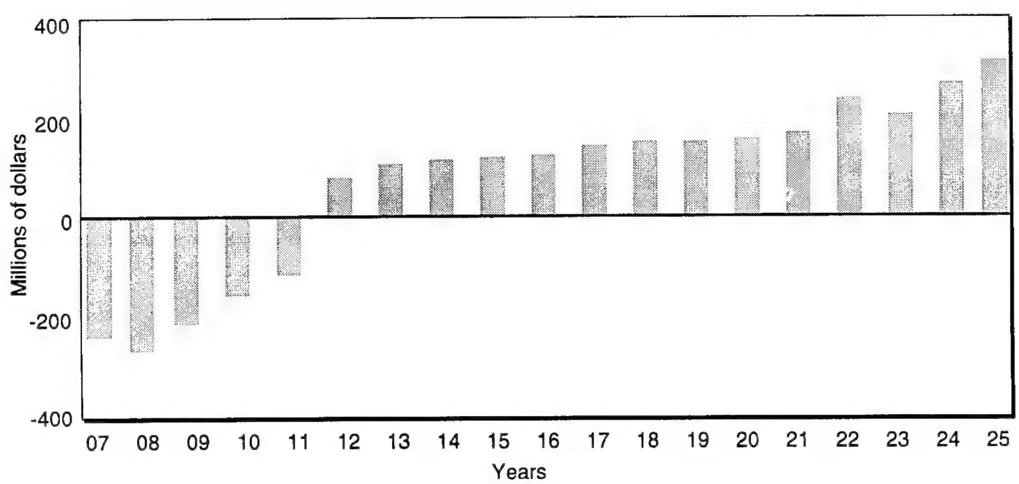


Figure 7.5.2-2 Annual Cash Flows From CTR Operations in Four U.S. Corridors For 20 Years (Millions 1994 Dollars)

Corridor	IRR	NPV
Northeast	11.7%	$21 million
Midwest	11.6%	$11 million
West Coast	8.5%	$1 million
Southwest	11.1%	$(6) million

Figure 7.5.2-3 After-Tax IRR and NPV at 10 Percent

An analysis was performed to measure the sensitivity of manufacturer and operator cash flow forecasts on rate of return to variations in key assumptions. Operator NPVs are calculated using a discount rate of 10 percent, while manufacturing program NPVs at break-even quantities are based on a discount rate of 12 percent. A summary of the results is shown in figure 7.5.2-4.

7.5.3 Airline Perspective on CTR

Existing airlines are most interested in recovering from the past few years in which they suffered unprecedented losses. Most carriers are returning to profitable operations and are now seeking to strengthen their balance sheets so that they are capable of financing needed investment such as replacement aircraft. Their focus is necessarily short term, and they find it difficult to speculate on likely market conditions 10 to 15 years in the future when CTR aircraft would come into use. Nevertheless, the CTRDAC felt it was important to determine the airline view of CTR aircraft.

New entrant airlines generally begin operations with used aircraft and are capital constrained. CTR represents a high entry-cost strategy because only new vehicles would be available for a number of years. In addition, most new entrants seek to exploit their inherent cost advantage over existing carriers and pursue low-fare strategies. To be successful, a CTR system must attract the most time-sensitive passengers who would be willing to pay more than the prevailing fare to save time. As such, the likely marketing approach for CTR most clearly resembles the market segmentation strategy used by FedEx (formerly Federal Express) when it first entered the overnight package business. FedEx delivered a premium service and charged prices above those for normal air cargo. Although FedEx had to build the pickup and delivery network, it did have access to used aircraft and existing airports. The CTR requires not only new vehicles, but also considerable new infrastructure in terms of conveniently located vertiports.

Airlines would require significant assurances on CTR performance, costs, and market potential before they will invest in CTRs and start service. Their concerns include:

- Infrastructure availability, including vertiports and air traffic control (ATC) at a reasonable cost.
- Vehicle operating cost, including fuel consumption and maintenance.
- Vehicle reliability.
- Passenger acceptance.
- Limited secondary market for CTR aircraft.

Non-Recurring Costs	Aircraft Selling Price	Operator		Manufacturer without Gov't R&D		Manufacturer with Gov't R&D		Break-even Year	Break-even Aircraft
		NPV at 10%	IRR	NPV at 12%	IRR	NPV at 12%	IRR		
$1.2 billion	$18.5 million	$27	11%	$(89)	11%	$273	23%	2013	506
	$17 million	$122	16%	$(233)	8%	$128	17%	2016	758
$1.8 billion	$18.5 million	$27	11%	$(205)	9%	$157	17%	2016	779

Figure 7.5.2-4 Sensitivity Summary

At the present time, there are too many unknowns about CTR acquisition costs, operating costs, and reliability in scheduled passenger service to generate strong airline interest in this technology. Airlines also may perceive greater downside risk regarding purchase of CTR aircraft because there may be only a limited secondary market for used CTRs.

Finally, most of the delay reduction benefits produced by CTR would not accrue to the operator of CTR aircraft, but to airlines and air passengers in general.

Interviews were conducted with executives of Southwest Airlines and FedEx to determine industry reaction to the CTR concept and to provide additional insight into issues that might require further research and development in order to gain carrier acceptance.

Within its current corporate structure, Southwest Airlines did not express an interest in operating CTR aircraft. Their current philosophy is to operate only a single, low-fare aircraft type and its derivatives in frequent, low-cost service. They expressed the belief that CTR is oriented towards the premium end of the market that is not the market segment that they are currently approaching. If they decided to operate CTRs, Southwest Airlines officials stated that they would consider establishing a separate company for this purpose.

Like Southwest Airlines, FedEx has a limited interest in operating CTRs, although they requested that they be kept informed of CTR development. They noted that the only significant role they saw for CTR at FedEx was in a small number of congested urban markets or if they sought to establish same-day package express service.

In addition to interviews with Southwest Airlines and FedEx, American Airlines was represented on the CTRDAC Economics Subcommittee as were individuals from two Wall Street firms active in aerospace and airline finance. These individuals indicated that they expected little near-term interest in CTR from airlines because airlines are currently concentrating on restoring the profitability of their existing operations. They also thought that some existing airlines might view CTR as a competitive threat. However, while this explains the lack of airline interest, it does not offer substantial insight on the economic viability of a CTR service to be introduced in 2007, other than to emphasize the difficulties of starting up a new transportation system.

The financial community indicated that any sort of air transportation-related financing ranks poorly relative to other private sector industries, owing to the low rates of return on investment in the air transportation industry. CTRs could be financed in the private sector, but it would require interest rates reflecting the low potential returns and the large downside risks associated with the lack of a secondary market for CTR vehicles.

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8.0 International Perspective

- The U.S. leads the world in CTR technology, but other countries could catch up quickly.
- The first country to manufacture a CTR could shut out other countries due to the smaller size of the total market compared to jet aircraft.
- Partnerships with other countries could reduce development financial risks.

8.1 Introduction

As discussed in Chapter 8 of this report, the estimated worldwide market demand for 40-passenger civil tiltrotor (CTR) aircraft ranges from 1,160 to 1,600 by the year 2010. This includes aircraft for scheduled CTR service in North America, Europe, Japan, and Oceania, as well as other nonscheduled applications worldwide, including package express, corporate, and search and rescue.

A market of this size would also be of interest to aerospace manufacturers in other countries. This chapter discusses the international competitive environment for the CTR, the current positions of the likely competitors to U.S. industry, and the various possible scenarios for this competition.

8.2 International Manufacturing Competition

While most analyses to date assume that U.S. industry would launch a CTR program, other countries have an interest in this technology.

- *United States Lead*

From a technical and manufacturing perspective, U.S. industry will be capable of developing and producing a 40-passenger, short-haul CTR aircraft by the year 2007 if recommended research is carried out. Since the 1950s, three generations of tiltrotor aircraft have been built and flown in the U.S. The latest, most advanced effort is the 45,000-pound V-22 Osprey under development for the Department of Defense. Now in the Engineering Manufacturing Development (EMD) phase, V-22 production is scheduled to begin by the end of this century and to proceed well into the next.

Bell Helicopter Textron (Texas) and the Boeing Helicopters Division of the Boeing Defense and Space Group (Pennsylvania) are teamed on an equal basis for the V-22 program. These are currently the only two U.S. companies with the technology in hand to design and build tiltrotor aircraft, although a broad-based U.S. industrial team is involved in many aspects of this project.

Bell and Boeing have invested a total of over $600 million in tiltrotor programs. They have stated an intent to work together on any size or class CTR project. As tiltrotor aircraft markets develop for one or more size aircraft, other companies may become involved. Some aerospace companies may elect to evolve their own technology base as independent producers. However, to provide a perspective on the size of the helicopter industry from which tiltrotor technology has emerged, 1994 sales for the whole helicopter industry totaled a reported $5.3 billion, representing only 3 percent of the output of the U.S. aerospace industry.

- *Europe*

In 1987, the European Council of Ministers designated the European Future Advanced Rotorcraft (EUROFAR) as a multi-nation effort to develop a tiltrotor aircraft. France, Germany, and Italy each have a 29 percent participation in a $38 million feasibility study. They are joined by the United Kingdom and Spain, each with a 6.5 percent interest. By 1992, these studies resulted in a plan for a $225 million development prototype aircraft with a target date of 1997. This recommendation was not approved. Aerospatiale of France contin-

ued work on the project and has built and wind-tunnel tested a scale model proprotor of an advanced design.

In April 1993, a new EUROFAR Phase II team began a definition phase for a 30-passenger commercial tiltrotor that is still underway. The Phase II team consists of French and German Eurocopter with a 67 percent interest and Westland from the United Kingdom with a 23 percent interest. This $10.8 million follow-on project was seen as the first step toward the first flight of a demonstrator by the end of the decade. Further goals include a production go-ahead in the year 2004 with first flight in 2006 and certification in 2009.

This European team has the technical competence to build and fly a tiltrotor aircraft. Funding will depend on government commitment which, in turn, is a question of political timing. If the European governments decide to subsidize a CTR, a EUROFAR tiltrotor could emerge as a strong, worldwide competitor similar to the emergence of Airbus for transport category airplanes.

The U.S. may have a 7- to 10-year lead over the Europeans for development of a commercial tiltrotor, but if government funding is made available to European manufacturers, much of this advantage could erode quickly.

- *Japan*

Japanese aviation industries have been watching tiltrotor development with a great deal of interest. While their aviation industry is only about 5 percent of the size of U.S. industry, it has demonstrated a high degree of technical and manufacturing skill in a wide variety of aircraft programs. Japanese aircraft manufacturers are very conscious of home market needs, especially for short-haul air transportation. A major study on the potential demand for a commercial tiltrotor is underway. This effort, underwritten by Japanese manufacturers, is scheduled for completion in late 1995. It can be expected to show significant potential demand but also to highlight that infrastructure issues in Japan are far more severe than in the U.S.

The Japanese aviation industry is very capable, having demonstrated the ability to produce superb quality products in many areas, including aircraft production. The Japanese Ministry of International Trade & Industry (MITI) provides a majority of start-up capital for favored projects, often through loans that are repaid on the basis of the degree of project success. While it is unlikely that the Japanese aviation industry would develop a tiltrotor aircraft independently, they would make excellent partners for projects which were aimed at producing CTRs for the Japanese market or other countries in the region.

- *Russia*

The Russian aviation aerospace industry is undergoing a significant restructuring and is financially constrained. Projects with world visibility, such as space exploration, consume all available government aerospace funds. The industry is undergoing a transition as Russia shifts to a market economy. It is believed that Russian industry has done predesign work and wind tunnel testing of the tiltrotor concept, but a Russian tiltrotor would not be expected to appear until well into the next century, and then perhaps as a joint development with another country.

8.3 Potential Partner Arrangements

The size of the tiltrotor market will limit the number of companies that elect to become involved. Due to large investments in time and the large negative cash flows in the early years of an aircraft manufacturing program, it is safe to assume that only major companies would launch a CTR program and then only when potential markets are well defined. For the U.S. market, the two existing tiltrotor manufacturers, Bell and Boeing, intend to remain teamed. Other aircraft industry suppliers are likely to establish partnership arrangements.

If the CTR market develops beyond current expectations, more than one source may emerge, especially a foreign manufacturer as suggested above. A number of scenarios are possible. There

is a trend in the U.S. commercial aerospace sector to establish relationships with non-U.S. companies in order to develop and build new-generation commercial jets. Typically this involves the participating companies providing investment funding to develop tooling to support their production activities. They expect to recover their investment from the sales of components they manufacture. This type of relationship provides a reduced exposure to the lead company and demonstrates a commitment to the project by all team members. There are clear motives for collaboration that can be identified from the substantial experience which now exists. These include:

- Improve market access in partner countries.
- Reduce financial risk for each partner.
- Reduce competition.
- Improve long-term business stability.
- Enable technology transfer.
- Increase product base.
- Expand market prospects.

The type of relationship relies on balancing these motives as perceived by each participating company.

Many parts and components of the CTR will have much in common with well established foreign aircraft manufacturing technology and methods. Composite materials, digital cockpits, and fly-by-wire controls are used and manufactured by companies abroad. It is only CTR design technologies that are unique to U.S. manufacturers.

To illustrate a number of possible competitive manufacturing scenarios, figure 8.2.5-1 shows a matrix of future international markets. Market division varies from Box 1, where there is no foreign source, to the other extreme in Box 4 where a foreign source has evolved prior to, or in lieu of, a U.S. source. This latter case is would result from U.S. industry delaying market entry or failing to exploit the market. This would be a monopoly market for a non-U.S. source, probably made possible by foreign government subsidies for the start-up and production phases of a CTR program.

CTRs with 100% U.S. content — 100% U.S. 100% foreign

1 U.S. dominated market	3 Fully competitive market
2 U.S./foreign shared market	4 Foreign-dominated market

50% U.S. content 50% foreign content — CTRs with 100% foreign content

Figure 8.2.5-1 Market Division Matrix

In between these two extremes are intermediate cases shown in Box 2 and Box 3. If, for a number of market reasons, foreign industry involvement is sought, the most likely situation is Box 2, where foreign aviation companies enter as subcontractors or suppliers on a U.S. CTR program. It would also avoid a situation where two manufacturers enter the market in competition with one another and neither program makes money. In later years, if a sufficient market exists to support a second manufacturer, a second CTR program could emerge. In that case, represented by Box 3, there would be a fully competitive situation in some markets, especially home markets, with less competition in others.

A more likely possibility is that a second (foreign) source might elect to sidestep direct competition by building a different size CTR aircraft than is available on the U.S. market. This would avoid price competition and the resulting reduction in producer profits. An alternate size vehicle would create a greater overall market for CTR aircraft and could actually increase the market for both sizes of aircraft as the technology matures and more infrastructure is developed. This would be a market characterized by both Box 1 and Box 4, one for each size CTR aircraft.

8.4 Summary

Positive steps by the U.S. Government in supporting the research base for the CTR could ensure that U.S. industry exploits its lead in this technology. In the event research funding is not provided, U.S. industry may forego some or all of this market. Foreign government financial support for its manufacturers, to take advantage of the market for CTR aircraft, could lead to the loss of a major industrial and technological opportunity for the U.S.

9.0 Societal Benefits

- Overall, it is estimated that CTR could provide a 15.5 percent real social rate of return. Total net benefits to society, including Government research and development, vehicle production, operations, and delay reduction could total $1.9 billion through the year 2027 (net present value (NPV) in 1995 at 7 percent).
- CTR production can also provide substantial employment and balance of trade benefits. It is estimated in the baseline scenario that there will be 684,000 employee years of employment associated with CTR production and $17.8 billion of exports over a 20-year period.
- Delay reduction benefits due to CTR could reach $1.2 billion through the year 2027 (NPV in 1995 at 7 percent).
- CTR offers large potential benefits to improve the use of scarce capacity at High Density Rule (HDR) airports.
- CTR fuel consumption and emissions will be slightly higher than conventional aircraft, but savings in aircraft delay reduction and in access/egress transportation may offset the difference.

9.1 Introduction

This chapter presents the results of the social viability assessment of civil tiltrotor (CTR) production and operation in the U.S. This assessment is structured in a benefit-cost framework developed to assess Government and private sector investments in aeronautics technology programs.[1] The methodology estimates the benefits and costs accruing to private parties and to society as a whole and includes the following assumptions:

- *Additional Research*

Additional research costing about $600 million over 10 years would be needed. To bracket the societal benefits, two scenarios were analyzed. The first assumed that Government would fund all research. The second assumed that industry would fund all research. Consistent with Government policy, it is anticipated that research will be jointly funded by Government and industry. When the Government pays for CTR research and technology development, the rate of return on the program is higher for the manufacturer.

- *Development and Production*

All development and production expenditures are made by the manufacturer who also must finance the negative cash flow of the program in the early years. It is assumed that sufficient vehicles will be delivered to U.S. operators to fulfill the market demand by 2012 with the remainder being exported.

- *CTR Operations*

U.S. operators buy CTRs and operate them using the revenue, operating cost, and market penetration results developed in Chapter 8 of this report. Only the benefits and costs of U.S. CTR operations are included as benefits to the U.S. economy.

- *Social Benefits and Costs*

This analysis also considers delay reduction benefits and costs of additional vehicle emissions as externalities that accrue from CTR operations but that are not reflected in the discounted cash flow of either the manufacturer or the operator. All benefits and costs are then considered to estimate the societal rate of return.

This chapter first covers other potential economic and social benefits of CTR production and operation in the U.S. as well as intangible benefits and costs. The remainder of this chapter discusses the cost-benefit analysis results in detail.

[1] Gellman Research Associates, Inc., Methodology for Estimating the Net Benefits of Technology Programs and Case Study Results, prepared for NASA under subcontract to ARC PSG (April 29, 1992).

9.2 Delay Reduction Benefits

9.2.1 Introduction

One of the major societal benefits likely to result from the introduction of CTR service is the reduction of delay at congested airports. Delay reductions could occur if airlines reduced the number of fixed-wing flights in proportion to the number of passengers diverted from jet and turboprop operations to CTR. The magnitude of these benefits is difficult to quantify.

By its nature, any analysis of airport delays is very speculative. Delay/capacity relationships are exponential in nature. After activity reaches the capacity of a facility, delays grow rapidly. Because some of the airports where CTR diverts demand are operating at levels close to their capacity, reducing conventional aircraft operations shows large projected reductions in delay.

While this study made use of the National Airspace System Performance Analysis Capability (NASPAC) model, the results obtained depend on assumptions about the future level of air travel as well as assumptions about how air traffic control (ATC) and airport capacity will be expanded in the future. It is therefore prudent to emphasize the uncertainty of the delay reduction estimates. The delay reduction benefits of the CTR have been estimated under two different assumptions about the level of delays in the future for two levels of CTR demand. In order to keep the analysis conservative, the lower estimate and delay reduction is used in the societal benefit-cost analysis. It is worthwhile to note that U.S. airlines estimate that delay imposes costs in excess of $3 billion per year on airlines and their passengers.

9.2.2 Estimated Delay Reductions

The baseline estimated delay reductions reflect CTR demand for vertiport-to-vertiport plus feeder services in the four U.S. corridors and exclude CTR demand for transfer traffic. Figure 9.2.2-1 shows the distribution of delay reductions at all airports modelled and in each of the four corridors examined in the CTR market analysis assuming that 1993 delay levels remain unchanged until 2010. The figure shows that most of the delay reduction occurs in the Northeast corridor and the Midwest. The delay analysis showed that daily operations at major corridor airports would be reduced by approximately 11 percent representing 650 flights. Delay savings would average 0.3 minutes per operation at large U.S. airports, with the majority of delay savings at airports in the Northeast. Figure 9.2.2-2 shows that these delay reduction projections, when applied to all scheduled domestic air operations, translate into annual delay savings of approximately 125,000 hours per year, or $160 million in reduced aircraft operating costs and $215 million in passenger delay cost savings.

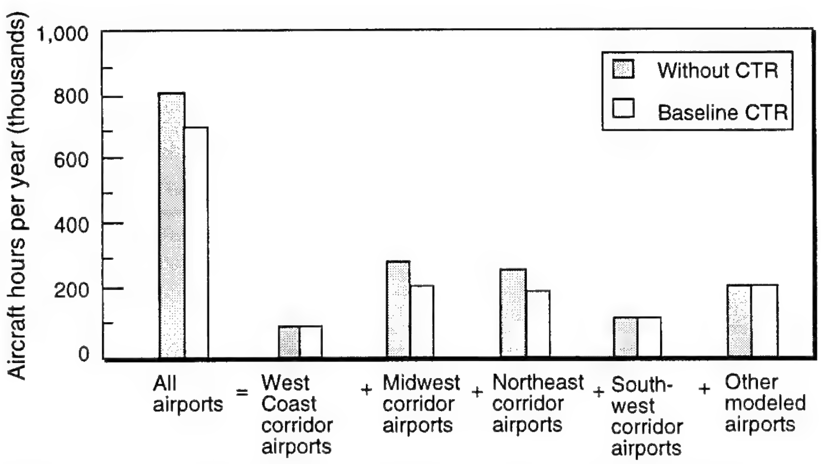

Figure 9.2.2-1. Projected 2010 Delays at 1993 Airport Congestion Levels

Type	2010 Annual Value of Delay Reduction
Aircraft operations	$160 million
Passenger time	$215 million
Total	**$375 million**

Figure 9.2.2-2 Annual Delay Savings Estimate From CTR Activity – Projected 2010 Traffic and Congestion Levels Using 1993 Delay Rates

Type	2010 Annual Value of Delay Reduction
Aircraft operations	$500 million
Passenger time	$850 million
Total	**$1350 million**

Figure 9.2.2-4 Annual Delay Savings Estimate From CTR Activity – Projected 2010 Traffic and Congestion Levels Using 2010 Delay Rates

In the case where the projected increases in delay between 1993 and 2010 are considered, delay savings were estimated to average 0.8 minutes per operation. Figure 9.2.2-3 shows the distribution of technical delay reductions at all airports modelled and in each of the four corridors for traffic and delay levels in 2010. There are significant delay reductions projected in the Northeast, Midwest, and West Coast, because forecast air traffic operations growth in these corridors is projected to exceed additions to capacity at several major airports in these regions. As shown in figure 9.2.2-4, this results in reduced aircraft operating and passenger delay cost savings, totaling approximately $1.35 billion per year.

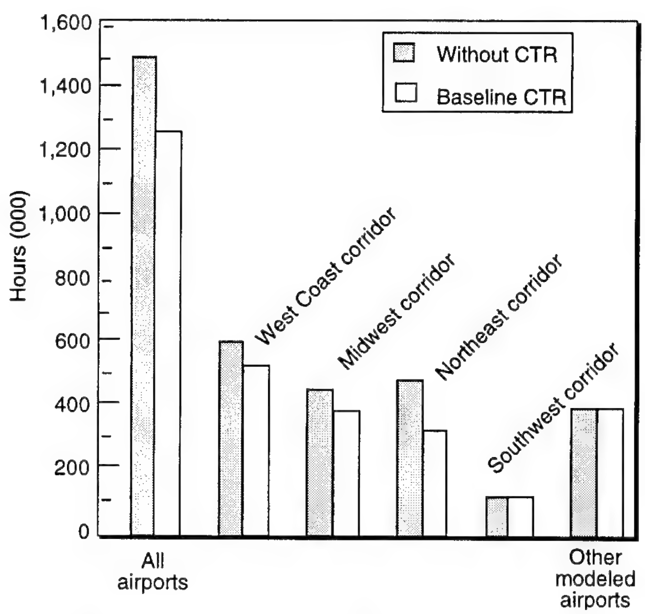

Figure 10.2.2-3. Year 2010 Delay Rates at Year 2010 Projected Traffic and Congestion Levels

As noted in the report of the CTRDAC Economics Subcommittee, the CTR delay reduction benefits would be over 50 percent greater than those shown below if CTR transfer traffic were included.

9.2.3 Limitations

There are several reasons why the baseline delay analyses might tend to overstate delay savings, especially when the Federal Aviation Administration (FAA) forecasts for the year 2010 are used. For these reasons the estimates based on 2010 delays could be considered as an upper bound on the delay benefits that might accrue to introduction of CTR service. These reasons include:

- The delay analysis included only near-term aviation technology improvements and planned airport capacity expansions until 2005. Any impacts of longer-term capacity enhancements, while not considered of major importance, were not included.

- The delay analysis did not systematically consider airline responses to increased airport delay and CTR competition. It is possible that airlines would either raise fares to reduce passenger demand or switch operations to less congested airports before delays at any given airport become excessive. This would likely result in lower average delays, but potentially higher CTR market share.

The substantial delay reduction benefits of CTR should be viewed in context. These benefits would accrue to a diverse group of aircraft

operators and air passengers. More importantly, only a small portion of these benefits are likely to accrue to carriers that acquire CTR aircraft. There are also a number of other possibilities that may be effective in reducing some or all existing or projected future delays, including:

- Airline actions, including the use of larger aircraft, increasing load factors, or pricing changes.
- ATC system improvements, particularly those that increase airport capacity in instrument flight rules (IFR) weather conditions.
- Development of additional airport capacity through improved operational procedures, construction of new runways, or development of new airports.
- Demand management strategies, including the use of appropriate prices for ATC or airport capacity to alleviate congestion.

For each of these options, there are significant costs involved. In addition, institutional obstacles constrain the extent to which these options can be expected to reduce delay. To the extent these policies result in increased prices for conventional air transportation, they also serve to make the CTR more price competitive and attract a higher level of demand than projected with the demand models.

9.2.4 CTR at High Density Airports

Demand for CTRs may be particularly strong at airports with capacity constraints that prohibit the addition of new flights at specific times without the subtraction of an equal number of same-time existing flights. In the U.S., there are four such capacity-constrained airports: Washington National (DCA), O'Hare (ORD), LaGuardia (LGA), and John F. Kennedy (JFK). They are governed by an FAA operational regulation referred to as the High Density Rule (HDR) that limits the number of aircraft operations that may be scheduled.

If CTRs were used to replace existing conventional airline flights in markets served by HDR airports, a primary benefit would be to free up jet and/or commuter slots. It is uncertain that the introduction of CTR service would ultimately lower overall congestion at the airports because the vacated slots could be filled by other flights. Indeed, carriers must meet certain minimum usage requirements or their slots can be transferred to another airline. Nevertheless, the additional air service capacity would still constitute a positive social benefit of CTR.

To assess the demand for CTRs at HDR airports, information was used on the profitability of flights on a carrier/city-pair specific basis for each HDR airport. This information was obtained from a previous analysis of HDR airports conducted for the Department of Transportation and FAA.[2] The HDR study identified specific additional flights that would likely be flown if more slots were available at HDR airports. Data on travel prices and costs were also obtained from this study.

The results for each HDR airport are shown in figure 9.2.4-1. The CTR appears to have significant potential to replace conventional flights at both DCA and ORD. The impacts at the two major New York City area airports, LGA and JFK, are much more modest. In addition, there were no instances where it was projected that new flights would be flown by CTR aircraft.

Airport	Number of Existing Flights ≤ 50 Seats, ≤ 500 Miles	Number of Existing Flights Switched to CTR	Number of New Flights Flown by CTR
DCA	158	37 (23 percent)	0
ORD	148	40 (27 percent)	0
JFK	234	2 (1 percent)	0
LGA	181	6 (3 percent)	0

Figure 9.2.4-1 CTR Demand at HDR Airports

[2] Federal Aviation Administration, Report to the Congress: A Study of the High Density Rule, May 1995.

The corresponding changes in economic welfare from replacing conventional flights with CTR are shown in figure 9.2.4-2. These changes represent net additions to producer and consumer surplus under the CTR simulation, and include the effects of the existing flights flown by CTR as well as new flights flown by conventional aircraft. In the figure, producer surplus refers to the profit generated by the additional fixed-wing flights made possible by CTR minus the change in profits from shifting existing flights to CTR.

Airport	Producer Surplus	Consumer Surplus
DCA	23	37
ORD	12	142
JFK	2	5
LGA	1	24
Total	**39**	**208**

Figure 9.2.4-2 Total Annual Change in Economic Surplus Due to CTR Operation at HDR Airports (In Millions of Dollars)

Consumer surplus is the difference between the total amount passengers are willing to pay for the service and the total amount they do pay. The estimates shown here reflect the *change* in consumer surplus that occurs due to CTR flights replacing fixed-wing flights and new fixed-wing flights being added. As new flights are added to existing markets, the full price of travel falls along the demand curve, leading to an increase in consumer surplus. Positive consumer surplus is also generated from flights in new markets.

The relatively high consumer surplus estimate for ORD is due to the fact that much of the new activity projected there involves flights to large international cities using large aircraft, thereby affecting large numbers of passengers.

This estimate of producer and consumer benefits of HDR airports is not carried forward to the societal benefit-cost analysis, because it would represent double counting in that the delay reduction benefits discussed in section 9.2 include activity at HDR airports. If, as shown in the analysis at HDR airports, additional conventional flights are added, the projected delay reduction benefits would not materialize. However, the additional service made possible by CTR would have value to producers and consumers.

9.3 Other Potential Economic and Social Benefits

CTR production could also impact U.S. employment and the balance of trade. However, because these factors are already included in the value of CTR production, they are not added separately into the societal benefit-cost analysis.

- *Employment*

CTR production would create additional employment in the U.S. The correct measurement of the effect on employment requires that analysts consider what alternatives these workers would have if a CTR program did not exist. In addition, employment effects should be considered net of any employment that occurs if the transportation service provided by CTRs is performed using other modes. This analysis does not support the estimation of employment impacts at this level of detail. However, many of the CTR passengers are diverted from conventional airline services that are currently provided by both jet and turboprop airplanes. Nearly all current-generation, large turboprop aircraft are manufactured in foreign countries, although some do contain U.S.-manufactured engines and avionics. Jet aircraft are produced in the U.S., Europe, and Canada, although most programs are multinational in nature. The total employment associated with the production of 1,160 40-passenger CTRs is estimated to be 648,000 employee-years over the 2007 to 2021 production period.

- *Balance of Trade*

Because it is assumed that CTRs would be produced in the U.S., export sales of these vehicles would improve the U.S. balance of trade. To the extent a U.S. CTR program evolved with overseas

partners, the foreign-produced content of the CTR should be excluded from export sales and included as a negative to the balance of trade for CTRs sold in the U.S. However, as noted above, the correct measure of these effects depends partly on how the transportation missions would be performed if CTRs were not used. It would then be possible to determine the net effect on U.S. exports from a commercial CTR program. These analyses are not developed to a level of detail to permit estimates of the net balance of trade effects. However, in the base scenario, it is estimated that export sales of 40-seat CTR aircraft would total $17.8 billion in 1994 dollars over the 2007 to 2021 time period.

9.4 Intangible Benefits

In addition to the quantifiable benefits resulting from the creation of a CTR regional air transport system, there are also qualitative benefits. The total value derived from CTR technology goes beyond its use in short-haul passenger transportation. These benefits could also be realized if other sizes of commercial tiltrotor vehicles were developed.

• *Retention of National Lead in Tiltrotor Technology*

The U.S. has developed the tiltrotor; other nations have not. As long as development and production continues, the U.S. will maintain an economically valuable lead over other nations in this aviation technology and retain an international trade advantage. There is no other aircraft product in the world in the enviable position of having no industrial competition.

• *Transportation Enhancement/Productivity Increase*

Increases in national/regional productivity might result from the introduction of CTR service. CTRs could allow the decentralization of industry in developing regions, moving industry to small communities that would have access to air service. In addition to this short-haul potential, CTRs could provide improved performance for package express services, corporate travel, air taxi flights, and other economic activity.

• *Disaster Relief*

A tiltrotor has high potential for use by the Federal Emergency Management Agency (FEMA) in hurricane, flood, and earthquake disaster relief. Runways are airports are often closed after a disaster strikes. Since the tiltrotor is not dependent on runways, it would be a valuable asset for transporting medical teams, food, water, and medical supplies and for providing medical evacuation.

• *National Defense*

CTRs could function in the current Civil Reserve Aircraft Fleet (CRAF) in which civil transports are equipped to operate for the Department of Defense in time of national need, such as the deployment of troops during Desert Storm. CTR aircraft in regional service could be equipped for potential diversion to national civil defense needs.

• *Public Service*

CTRs could also be used by the Coast Guard in the drug interdiction mission. Tiltrotors could replace the present combination of three different types of aircraft required for the search, tracking, and apprehension functions required in this ongoing activity. Because of its speed and vertical flight capability, the tiltrotor could also outperform fixed-wing aircraft or helicopters in environmental surveillance, search and rescue, and border patrol missions.

• *Resource Development*

Our national needs require that additional indigenous oil reserves be identified and exploited. The tiltrotor would allow oil exploration and development at greater offshore distances than is practical with helicopter support. Tiltrotor aircraft also offer the oil industry a unique and timely means to respond to the control or containment of oil spills at sea. Properly equipped tiltrotor aircraft could deploy to any point in the world in a matter of hours to help contain a spill at sea.

• *CTR/Military Operational Performance Feedback*

The high utilization rate of civil helicopter fleets has resulted in lessons learned and improve-

ments that were then applied to improve similar military helicopters. CTR aircraft will provide similar valuable information and innovation to improve V-22 military capability and readiness. In addition, the proposed CTR research and development program would also benefit future military tiltrotor aircraft.

- *Research and Development Spinoffs*

Some of the research and development program proposed for the CTR could benefit future helicopter and airplane models. In particular, work on a low-noise rotor, one-engine-inoperative (OEI) operations, and navigation and landing systems could be applied to future helicopters.

9.5 Energy and Emissions Impacts

Energy and emissions impacts are two important societal consequences associated with the introduction of CTR service. The market analysis projects that the CTR will likely divert a substantial number of intercity passengers from other modes of transportation, principally jet and turboprop air travel. Because CTR is expected to use slightly more energy per seat mile and produce slightly more emissions than jet aircraft, the introduction of this new service will have implications for the total amount of transportation energy used and emissions released. A complete discussion of energy and emissions can be found in Chapter 6 of this report. The remainder of this section is devoted to the economic consequences of the slightly increased levels of energy consumption and emissions generated by CTR.

Based on a price of $0.60 per gallon for aviation fuel, the estimated dollar value in 2010 of increased energy consumption due to diversion of passengers to CTR is approximately $21.9 million in 1994 dollars. This averages about $2.10 per CTR passenger.

Figure 9.5-1 shows estimates of emission changes resulting from the introduction of CTR vertiport-to-vertiport service in the year 2010. The estimated reduction in emissions of oxides of nitrogen is due to projected improvements in CTR engine technology. The monetized values of emissions changes are based on estimates of average control costs to reduce mobile and fixed point emissions by the best available existing technologies.

The estimated societal cost of added emissions due to CTR service in 2010 is approximately $5.3 million, or about $0.50 per CTR passenger. These emissions estimates assume that current engine emission technology is used on all jet and turboprop aircraft.

9.6 Societal Benefit/Cost Analysis

The analysis of societal returns uses a discount rate of 7 percent for all benefits and costs. This includes manufacturer and operator cash flows that

Market Area	Change in Emissions (tons)			Dollar Cost (in millions)
	HC	CO	Oxides of Nitrogen	
Northeast	+68	+240	-202	+3.1
Midwest	+37	+130	-163	+1.8
West Coast	+18	+55	-98	+0.4
Southwest	+3	+10	-10	-0.02
Total	**+126**	**+435**	**-473**	**+5.3**

NOTE: for vertiport-to-vertiport plus feeder travel (11.2 million passengers)

Figure 9.5-1 Estimated Changes in Aviation Transportation Emissions After Introduction of CTR for the Year 2010

are discounted at higher rates when considering private benefits and costs.

The total net present value (NPV) in 1995 of delay and environmental effects, discounted at 7 percent through the year 2025, is approximately $1.22 billion. This is based on the assumption that the base delays per flight in the year 2010 are the same as in 1993. Corridor-specific estimates are:

- Northeast $790 million
- Midwest $350 million
- West Coast $80 million
- Southwest -$1 million

The net social benefits from delay reduction and environment effects are quite large, with an NPV of over $1.2 billion in 1995 dollars. Figure 9.5-2 summarizes the components of social returns in the Base Case scenario by corridor and type of benefit.

A discounted cash flow analysis composed of four modules makes up the CTR economic and social viability assessment. These modules include government research and development (R&D), manufacturing, operations, and delay plus environmental effects. The analysis in Chapter 7 of this report shows that ATC and vertiport infrastructure may be self-financing. These costs are included in the CTR operating costs and demand models. As such, they are not included separately in the societal benefit-cost analysis.

The R&D cash flow is assumed to begin in 1995 and spans 8 years with total expenditures of approximately $600 million. Private manufacturer development costs are assumed to begin in 2003 and cover a 4-year period with total expenditures of $1.2 billion. Aircraft deliveries are projected to begin in 2007 and continue for a total of 16 years with a total production run of 1,110 aircraft. The CTR unit price is assumed to be $18.5 million and break-even occurs on the 506th aircraft based on a 12 percent rate of return. It is also important to note that any net losses are assumed to be expensed in the year of the loss for tax purposes. Based on Government funding of R&D, the NPV to society in 1995 of vehicle production is $900 million when discounted at 7 percent. Based on these assumptions, the after-tax internal rate of return (IRR) of manufacturer cash flow after the full production run is approximately 22.2 percent. This excludes the assumed $600 million R&D expenditure by the National Aeronautics and Space Administration (NASA) and FAA. If these costs were instead incorporated into manufacturer cash flow, the full production IRR would fall to approximately 10.6 percent. If only 500 units were produced and the manufacturer paid all the R&D costs, the IRR would fall from 12 percent to approximately 0.4 percent.

The operations cash flow is broken down by corridor. The Base Case scenario, which includes vertiport-to-vertiport and feeder operations but excludes transfers, is used for the operator cash flow. Depending on the corridor considered, operations are assumed to begin in 2007 or 2008 and build to the demand projections by 2011 or 2012.

Corridor	Aircraft Delay	Passenger Delay	Environmental	Total Savings
Northeast	$460	$360	$(30)	$790
Midwest	$220	$150	$(20)	$350
West Coast	0	$90	$(10)	$80
Southwest	0	0	$(1)	$(1)
Total	**$680**	**$600**	**$(55)**	**$1,220**

NOTE: discounted at 7 percent through year 2025

Figure 9.5-2 Base Case Scenario Summary of Net Present Value of Delay Reduction and Emissions Increases (In Millions of Dollars)

The operations are then assumed to grow 1.5 percent annually through the end of the cash flow analysis in the year 2025. This is consistent with the average growth rate across all corridors shown in figure 7.3.4-1. In all cases, CTR aircraft are assumed to have a useful life of 15 years, after which they are replaced by new CTRs.

Under the above assumptions about CTR operations and the results reported in Chapter 7 of this report, the estimated return to CTR operators in the four U.S. corridors was calculated. As shown in figure 9.6-1, the estimated IRR ranges from 8.5 percent in the West Coast corridor to 11.7 percent in the Northeast corridor. The NPV in 1995 of CTR operators totals approximately $175 million when discounted at 7 percent.

Corridor	IRR	NPV
Northeast	11.7%	$106 million
Midwest	11.6%	$56 million
West Coast	8.5%	$10 million
Southwest	11.1%	$4 million

Figure 9.6-1 After-Tax IRR and NPV at 7 Percent

Societal Return on Investment and Private Net Present Value—Combining these social benefits with the potential returns for both manufacturer and operators, it is possible to calculate an overall social cash flow. The resulting cash flow has an overall NPV of approximately $1.86 billion using a discount rate of 7 percent (figure 9.6-2). The real rate of return on this cash flow is approximately 15.5 percent.

The overall societal benefit-cost analysis makes use of the lower (1993) delay reduction estimates. Although the present study makes use of available information, further research into CTR delay reduction benefits is warranted because of their importance in the projected level of societal benefits.

These delay reduction benefits accrue to all air passengers and aircraft operators at airports where

Category	Government-Private NPV (millions of $)	Societal NPV (millions of $)
Government/industry research and development	$(435)	$(435)
Industry vehicle production (discounted at 12 percent for private NPV and 7 percent for societal NPV)	$273	$900
Vehicle operations (discounted at 10 percent for private NPV and 7 percent for societal NPV)	$27	$175
Delay reduction	$1,230	$1,230
Infrastructure	0 *	0 *
Total	**N/A**	**$1,860**

* Self-financed from CTR operator fees and passenger ticket taxes and/or user fees.

Figure 9.6-2 Base Case Scenario Summary of Net Present Values in 1995

CTR diverts demand for conventional air flights. However, because few if any of these benefits accrue to the operator investing in CTR aircraft under current institutional arrangements, the operator will not consider these benefits in its investment decisions. If airport landing fees reflected the effect of congestion on other operations, this would raise the cost of conventional air operations at airports prone to delay. If the airport proprietor also operated a vertiport, these additional landing fees could be used to offset part of the vertiport costs. This would provide additional incentives for operators to acquire CTRs.

Figure 9.6-2 also shows NPVs for manufacturers and operators at their typically higher discount rates. These higher rates assume that private investors will require a risk premium to invest in CTR production and operations. The NPV for manufacturers at their 12 percent representative discount rate is $273 million. The NPV for CTR operators at their 10 percent representative discount rate is $27 million. These NPVs result in what could be considered adequate return on investment for both manufacturers and operators.

The NPV of the delay reduction benefits are about four times the R&D investment needed for CTR development. The R&D investment will not guarantee the large NPV of the program because other elements of the program must be accomplished for success. However, without the investment in R&D, there would be a very low probability of CTR development in the time frame envisioned.

10.0 Risks and Uncertainties

- There is little doubt that the required levels of CTR performance can be achieved, but there is significant risk that the necessary R&D could exceed current time and cost estimates.
- Failure to obtain satisfactory demand-center locations for vertiports for environmental or other reasons would compromise the commercial success of CTR services.
- CTR acquisition, operation, and maintenance costs could exceed estimates, weakening overall economic viability.
- Changes in airline price structure, including those in response to CTR services, could diminish the ridership and economic viability of CTR service.

The speed and success with which new technologies and operational concepts can be introduced into transportation systems is strongly affected by the degree of innovation involved. Transportation technology most often advances in an incremental manner in which the likely consequences of new or improved vehicles can readily be estimated with reasonable confidence as in the case of jet aircraft or diesel locomotives. New operating patterns or transportation markets can usually be tested using existing infrastructure and leased or secondhand equipment, and vehicles can easily be sold in the event of commercial failure. The civil tiltrotor (CTR) case presents a major challenge, since none of these conditions exist.

New vehicles will have to be developed, manufactured, and certified but will have a very limited market if the other conditions for CTR services are not met or if demand is inadequate. New vertiports and airspace management changes will be necessary. CTR service will differ significantly from existing air, rail, and highway modes, and the cost to passengers cannot be predicted with confidence, complicating the task of estimating ridership. For these reasons, although the Civil Tiltrotor Development Advisory Committee (CTRDAC) has confidence in the validity of its findings and recommendations, many uncertainties remain.

10.1 CTR Technology Risks and Uncertainties

There is little uncertainty concerning the ability of the aeronautical technical community to create a CTR that meets the level of performance on which this analysis is based. The most challenging area is likely to be in reduction of noise levels. Meeting regulatory standards may not be sufficient to overcome community concerns, requiring further reduction in noise levels.

While no inherent safety limitations have been found for CTR, achieving both certification and public confidence may be complicated by the need to demonstrate sufficiently high levels of safety to overcome a negative perception of helicopters and commuter aircraft, however unwarranted. Similarly, a CTR should be able to meet reasonable emission requirements, although a future stiffening of air quality control measures or concerted attempts to constrain carbon dioxide emissions could pose demanding challenges to CTR propulsion systems.

While the level of technical risk is considered low, development of any new technology is a challenging undertaking with a potential for delays and unplanned expenses in the research, development, test, and initial manufacturing phases. Of greater concern is the possibility that in order to meet all CTR requirements, the aircraft might ultimately have higher capital and operating costs than are currently assumed. This would reduce the economic attractiveness of CTR service. Also, the assumed price range for a CTR of $17 to $20 million includes sizable anticipated manufacturing

efficiencies worth over $4 million per aircraft. It has been claimed that recent manufacturing technology innovations will lead to significant cost savings in the production of both aircraft and helicopters, but these claims have not yet been fully validated.

10.2 Economic Viability Risks and Uncertainties

The analysis of the commercial viability of CTRs in the U.S. is based on many significant assumptions, including the state of the intercity transportation market in the early part of the 21st century after CTR introduction and the characteristics and costs of CTR aircraft. The committee also made assumptions on needed air traffic control (ATC) services and responses of CTR and other airline operators. Because these assumptions relate to conditions as they will exist in the future, there is uncertainty and risk surrounding the accuracy of the resulting predictions. Some of these risks have been examined through sensitivity analysis, while others are less subject to quantification. In several cases, sensitivity to key assumptions is relatively large, contributing to uncertainty in critical analytical results relating to economic viability and availability of financial resources. Section 7.3.7 of this report contains a discussion of ridership sensitivity analysis.

Major areas of risk include:

- *Conventional Airline Price Structure*

CTR operational viability has been found to be highly dependent on the level of conventional airline prices. Recent trends indicate that the spread of low-cost airlines into new markets and the more frequent use of contracted fares might lead to a reduction in overall airfares in future years. These trends were not applied to our future CTR operating concept. On the other hand, the need to replace older aircraft and the added costs of doing business in more congested airspace might result in increases in airline costs and increases in future airfares.

- *Airline Competitive Response*

In addition to variation in airline fares due to changing costs, there are numerous possible responses by the airlines to competition from CTRs. These competitive responses are not well understood. Fare reductions to keep market share are certainly possible, but so are changes in amenities, frequent flyer inducements, and yield management approaches. Fare reductions are typically used to counter the reduced fare of a competitor. In the case of CTR, the fare will already be higher than a comparable fixed-wing fare. This variability in future conventional airline fares is the cause of uncertainty regarding CTR viability.

- *Siting of Vertiports*

Vertiport siting is an important issue in assessing CTR viability. Limiting the number and/or desirability of vertiport locations has been estimated to lead to as much as a one-third reduction in CTR ridership. In the extreme, CTR service would not be viable if suitable vertiport sites were not available.

- *Initial Start-up Costs*

Both helicopter and conventional airline operators indicate that costs of providing CTR service would likely be much higher during the initial months of regular operation due to extra training and certification costs and operational break-in inefficiencies. Potential CTR operators would have to have sufficient financial reserves to make it through this less profitable start-up period.

- *Future Air Travel Demand*

Projecting future air travel demand relies on forecasts of regional increases in population and aggregate income, as well as the variation in future airline price levels. There is considerable inherent variability in these forecasts when extrapolated 15 to 35 years into the future. In addition, the analysis assumed no impact on air travel demand growth from the substitution of technologies such as video conferencing.

- *Connecting Service*

Another concern involves projecting the availability of connecting air service that is significant in many markets, especially in the Midwest. Much of the currently available connecting service is the result of the current airline hubbing structure. If hub locations were to change significantly or the airlines reverted to more direct flight itineraries, a significant share of the potential CTR transfer passenger traffic might disappear. It should be noted that transfer traffic was not used in the operator economics or social benefits analysis.

- *CTR Operational Efficiency*

Because business travel is more concentrated over fewer days of the week than non-business travel, it will probably be more difficult for a CTR operator to consistently achieve high-load factors and high aircraft utilization. Deterioration in either of these areas results in significant increases in projected CTR operational costs and fares and subsequent reductions in projected ridership.

- *CTR Sales Price*

The estimated CTR selling price of $18.5 million per unit allows the manufacturer to break even if 506 units are sold over A 10-year period, assuming a required 12 percent real rate of return and nonrecurring costs of $1.2 billion. This quantity is less than one-half of the lower range of projected worldwide demand for CTRs in the year 2010. If quantities sold exceed this level or if higher prices are realized, the rate of return would increase. Higher development costs or lower sales quantities would reduce the rate of return.

- *Risk Compounding*

CTR commercial success is vulnerable to failure due to risk compounding. A successful CTR requires that a large number of unknowns be resolved favorably while a negative resolution of only a few unknowns could result in failure.

10.3 Infrastructure Risks and Uncertainties

Because vertiport location is considered critical to the attractiveness of the CTR mode and its financial viability, community acceptance is extremely important. However, firm conclusions on aircraft design as well as vertiport and operational characteristics required cannot be reached until a prototype aircraft can be demonstrated, specific candidate sites selected, and a clear picture of CTR operations developed. While noise concerns dominate the discussion, a wide variety of other topics are likely to be raised, including land use, traffic congestion, and safety, as well as preservation of habitat, wetlands, and historic sites. Some key vertiport locations may simply not be available. Resolving these issues may require mitigation efforts, operational changes, or selecting some less attractive sites. All of these activities could extend the time frame for implementation of service. The potential for long delays of this type can serve as a serious deterrent to initiation of vertiport projects and investments by CTR-based carriers.

CTR line-haul times are estimated to be faster than turboprop and competitive with many existing scheduled jet aircraft travel because it is assumed that CTRs will fly more direct routes between vertiports than conventional aircraft do between airports. It is also assumed that CTRs will not be subject to the terminal area delays that lengthen conventional air travel times in many congested metropolitan areas. The validity of these assumptions depends on introducing CTRs into the ATC system in ways that maximize CTR capabilities.

10.4 Institutional and System-Level Risks and Uncertainties

There are a wide variety of decisions and major financial commitments that must be made for CTR service to become a reality. These decisions and commitments must be made by independent public- and private-sector entities, including manufac-

turers, vertiport developers and operators, new or existing air carriers, Federal regulators, research and development organizations, and others. The ultimate viability of the CTR depends on a multitude of factors that will drive key governmental and corporate decisions, including:

- The decision to develop a demonstrator CTR.
- The decision to manufacture a CTR.
- Decisions on appropriate locations to construct and operate ground facilities.
- Local decisions to allow CTR operation.
- Decisions regarding airspace management and associated regulations.
- Corporate decisions to provide CTR-based passenger transportation services.
- Financial decisions to invest in CTR companies.

These decisions, involving many parties, are tightly linked. The risks and uncertainties facing any one entity reflect not only the underlying realities, but also the perceptions of the other participants in the overall enterprise. Lack of confidence in what decisions others may make in the future could increase the level of risk perceived by each party to the point that no CTR initiative would proceed, even if none of the potential risks proved to be valid. The basic system-level uncertainty concerns the ability of the various tiltrotor stakeholders and participants to work closely together in a coordinated manner, each being willing to make and carry out substantive long-term commitments.

11.0 Research and Development

- An expanded, $600 million, shared-cost Government/industry research program is needed to develop the critical noise, cockpit, engine/drivetrain, composite structures, and infrastructure technology to assure early U.S. manufacture and introduction of CTR.
- The research program should be in two phases. The second phase, a demonstrator aircraft, would be undertaken contingent on the success of the first phase.
- A program to fly a CTR demonstrator aircraft is essential to determine community acceptance.
- Infrastructure research is also needed to address ground facility design and air traffic control issues.

As described previously, tiltrotor technology has yet to reach the stage that would permit the development of an economically viable 40-passenger civil tiltrotor (CTR) that would be acceptable to surrounding communities. Before U.S. industry can build a successful CTR, there must be further advances in external noise reduction, contingency engine power, flight control systems, internal noise/vibration reduction, composites, manufacturing, systems condition and usage monitoring, and icing. These advances in technology are achievable and should be demonstrated to the public by a flying prototype by the year 2001. This would provide the most information prior to a production decision and would sustain the U.S. competitive lead over European manufacturers. This will allow an informed go/no-go decision by all parties concerned by the year 2003. The Civil Tiltrotor Development Advisory Committee (CTRDAC) recommends a phased approach to the required research and development that could be terminated after Phase A if the results do not show a promise for CTR community acceptance and economic viability.

CTRDAC research and development recommendations were developed after a great deal of discussion among committee members, especially those members from the helicopter manufacturers, airport authorities, the Federal Aviation Administration (FAA), and the National Aeronautics and Space Administration (NASA). A great range of options were considered. Although only two of the U.S. helicopter manufacturers, Bell and Boeing, were represented by committee members, McDonnell Douglas and Sikorsky also freely shared their views with the committee and added significantly to the overall discussion.

11.1 Aircraft Research and Development

The CTRDAC recommends the two-phase approach to research and development shown in figure 11.1-1 and described in the following paragraphs.

11.1.1 Phase A

Phase A (figure 11.1.1-1) would accelerate the ongoing $63 million research program and augment it with an additional $220 million. The resulting program would be a new $283 million technology research program ending in the year 2000. It would be mostly a ground test program with the possibility of some flight testing. The cost would be shared by Government and industry. The program would include:

- Wind tunnel and early flight testing of a low-noise rotor, including autorotation tests and an assessment of rotorwash/wake vortex velocity and direction.
- Drive train and contingency engine power concept ground testing of advanced con-

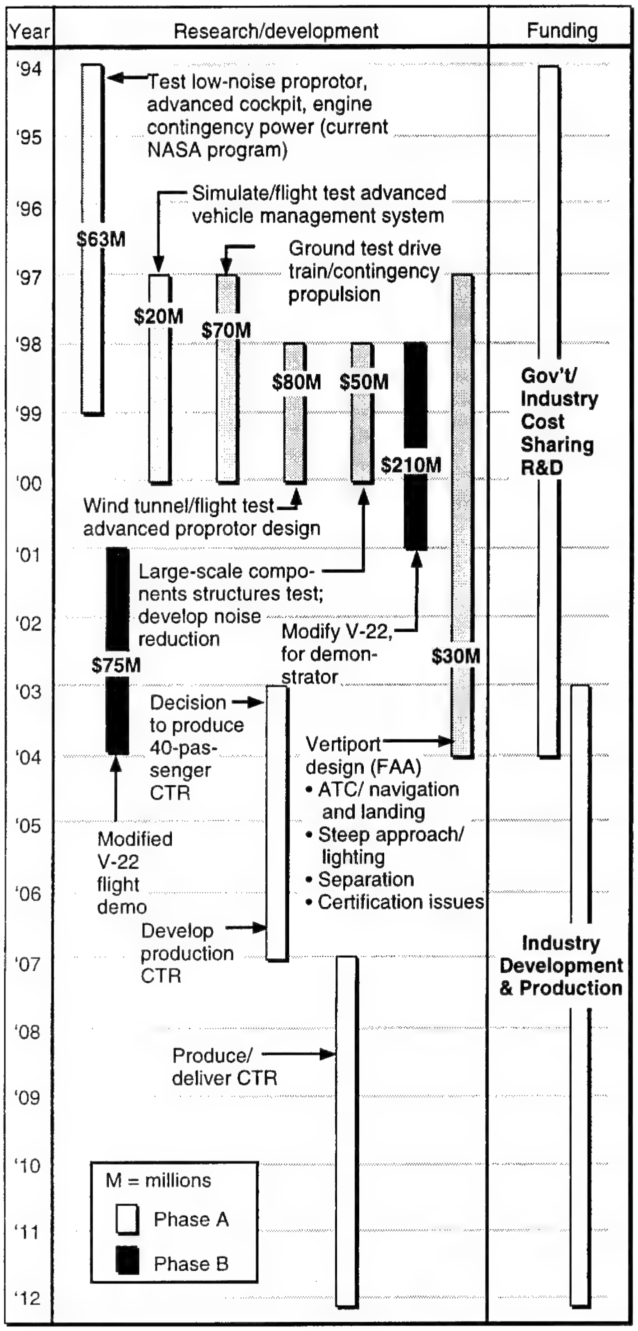

Figure 11.1-1 CTR Research and Development

cepts, including advanced concepts of a systems condition and usage monitoring system for critical engine, structure, and drive train components.

- Simulation testing, and possible flight testing, of an advanced cockpit and vehicle management system, including human factors research for the flight deck.
- Internal noise and advanced vibration reduction concept tests.
- Large-scale component tests of composite wing, fuselage, and tail concepts.

11.1.2 Phase B

A modified version of the V-22, that has most of the important civil features, must be demonstrated so that actual noise levels can be measured and experienced by several local communities. A demonstrator could also be flown by potential operators to make an assessment of how it would meet their needs. FAA pilots could also fly the demonstrator to gain an early look at aircraft certification and safety issues.

The purpose of Phase B (figure 11.1.2-1) is to combine all of the separate technologies developed in Phase A into a flying prototype that can be demonstrated to local communities and potential operators. Phase B would be financed by a cost-sharing arrangement between Government and industry.

There was extensive discussion by the CTRDAC whether to use a highly modified XV-15 or a highly modified V-22 as the flight demonstrator aircraft for Phase B. There are benefits to using either alternative. The XV-15 is approximately the size of a potential nine-passenger tiltrotor while the V-22 is very close in size to a 40-passenger CTR. To remove any doubt about the scaling factor regarding noise, it was decided that a highly modified V-22 would produce the optimum data. It is also believed that local communities would rather see a vehicle the same size and weight as a potential CTR than the much smaller XV-15.

The first part of phase B would be the modification of a V-22, which would be taken from the production line and outfitted with a low-noise rotor, advanced cockpit, and a small number of commercial passenger seats. Purely military items, such as the folding mechanism for the wing and proprotor blades, and armored crew seats, would be removed.

Program	Time Line	Cost	Description
Ongoing NASA research	1994 - 2001	$63 million	• Currently funded. • Model scale testing of low-noise proprotor technology, advanced cockpit, increased engine contingency power. • Schedule would be compressed to 1994-1999 time frame to support next phase.
Augmented program	1997 - 2000	$220 million	$80 million— • Advanced proprotor design, wind tunnel test and early flight test with appropriate flight test vehicle (1998 start).
			$20 million— • Advanced vehicle management system development using simulation and/or flight testing (1997 start).
			$70 million— • Drive train and contingency engine propulsion concepts demonstrated in full scale integrated ground tests (1997 start).
			$50 million— • Composite wing, fuselage, and empennage structures concepts validated in large-scale component tests (thin gauge and dynamically tuned structures). • Development of internal noise/vibration reduction mechanism (1998 start).
Total $283 million			

NOTES:

- The ongoing NASA program is already funded for $63 million
- If the augmented program is funded, the ongoing and augmented programs would be combined into a comprehensive, integrated, single program for a total combined cost of $283 million
- In the augmented program, the level of industry participation will determine how many rotors and what scale will be tested in the wind tunnel and in flight test. The data from this portion could be used to support a range of civil tiltrotor sizes (from 9 to 40 seats)
- The transmission would be developed for the optimum configuration that will benefit the next phase of this program (V-22 flight demo). The XV-15 flights would be with a minimum modification to the existing transmission

Figure 11.1.1-1 Phase A Research and Development

Program	Time Line	Cost	Description
CTR flight demonstrator	1998 - 2001	$210 million	Highly modified V-22 development, assembly, and initial flight operations: • Advanced proprotor and drive system technology from previous program • Commercial 9-passenger cabin • Upgraded cockpit
	2001 - 2003	$75 million	Flight demo of modified V-22. Assumes flight demo cost of $2 million per month for 3 years
Total $285 million			

Figure 11.1.2-1 Phase B Research and Development

This configuration would then be flown by Government and industry test pilots to determine the flight characteristics and establish a safe operating envelope. If considered beneficial by industry and the FAA, some autorotation work could also be performed at altitude.

The second part of phase B would include a flight program for the highly modified V-22 in a series of demonstrations in local communities. The committee believes that this type of real world, hands-on demonstration would be absolutely essential to gain knowledge related to community

acceptance, particularly in the areas of noise and safety. Noise and rotorwash measurements would be taken at this point.

11.1.3 Industry Research and Development

The committee anticipates cooperation between industry and Government for Phase A and Phase B. There are four additional areas industry should pursue largely on its own:

- *Fly-by-wire flight controls*

This research should be accomplished during the Phase B modification of the V-22. Industry should also monitor ongoing NASA fly-by-light flight controls research. The final selection of a flight control system design can be delayed until an industry decision to produce a production prototype and perform certification tests. This would be monitored by FAA.

- *Training requirements*

Training requirements could be developed during Phase B and during the certification flight testing of the production prototype aircraft which would constitute the industry-led follow on to Phase B.

- *Icing*

Development of a CTR deicing and anti-ice system should be accomplished during industry-led follow-on to Phase B. NASA is continuing research into ice accretion computer codes validated by wind tunnel tests, although this research is not devoted specifically to tiltrotor.

- *Advanced manufacturing techniques*

Investigation should be done concurrent with Phase A and B.

11.2 Infrastructure Research and Development

Infrastructure research and development work is also required. This would be supervised by the FAA and would require an additional $4 million per year during the years 1997 through 2004. This would include:

- Terminal Instrument Procedures (TERPS), including Category 2 and 3 operations.
- Standards for designing and implementing airspace around vertiports.
- Air traffic control (ATC) procedures.
- ATC tower establishment criteria.
- Aircraft separation standards on approach to vertiports.
- Updating vertiport design Advisory Circulars (AC), including land-use planning, capacity, lighting and marking, touchdown lift-off surface (TLOF) instrument flight rules (IFR) separation, and separation standards for TLOFs/final approach and take-off areas (FATO)/taxiway.
- Code of Federal Regulations, 14CFR77, "Objects Affecting Navigable Airspace",for vertiports.

12.0 Institutional Framework For Implementation

- Actions by many entities are required to implement a new transportation system such as CTR.
- There is no organizational entity with the authority to coordinate Government and industry activities necessary to implement a CTR transportation system.
- A public/private partnership is recommended, involving the Federal Government, state and local governments, airport interests, and CTR manufacturers. All parties would provide financial resources for partnership activities and the Federal Government share would be modest.
- The CTR should be included in analyses of transportation improvements for specific heavily traveled corridors.
- All transportation options, including the CTR, should be examined to determine which solution or combination of solutions are most appropriate in economic, environmental, safety, and other dimensions.

12.1 Coordination of Entities and Their Roles

Actions by a number of entities are required to implement a civil tiltrotor (CTR) system for intercity scheduled passenger transportation using 40-passenger aircraft. These entities include CTR manufacturers and operators, the National Aeronautics and Space Administration (NASA), the Federal Aviation Administration (FAA), local planning authorities, airport operators, and the aviation financial community. Coordinating these actions is perhaps the greatest challenge to achieving a CTR transportation system. Aircraft manufacturers will be required to invest well in excess of $1 billion to launch a production program for a 40-passenger CTR. Manufacturers will not undertake such a program until technical and market risks are viewed as manageable. This requires that the development of CTR technology continue to reduce external noise and improve safety. It also requires that operators place launch orders in sufficient quantities to justify manufacturer investment. At the same time, CTR air and ground infrastructure enhancements must be shown to be available on a reasonable timetable for CTR implementation.

Technical risk reduction will require Government action. Government support is crucial because of the type of research and development (R&D) required and the return on this R&D investment. If manufacturers had to pursue this R&D alone, it is likely the effort would not take place in the near future. At the same time, however, the NASA aeronautics research program is facing an uncertain future and is affected by the pressures to reduce Government spending. Industry may be required to assess the priority of NASA funding for CTR research in light of other NASA investments in aeronautics research. FAA support of safety and navigation system R&D for CTR will also likely be required.

Local planning authorities and airport operators will control general infrastructure development for CTR. Their involvement will be necessary to plan and fund the development of vertiports. Two types of ground infrastructure development are necessary:

- Initial infrastructure for the CTR start-up phase of operations, which involves the expansion of existing heliports and making necessary improvements to accommodate CTRs at existing airports
- Planning and development of large vertiports that will be needed as the CTR system matures.

Ground infrastructure decisions are inherently local in nature and must take into consideration the

economic, environmental, financial, and safety issues raised by CTR operations. Local authorities will need to see that CTR technology can be developed to mitigate adverse environmental impacts. Airport operators could play a key role in financing a mature system of vertiports because CTR provides congestion alleviation benefits at existing airport facilities. On the other hand, the airlines operating at existing airports might oppose vertiport development unless they also operate CTRs.

Airports use funds they receive under the Airport Improvement Program (AIP) and Passenger Facility Charges (PFC) for vertiport development in order to reduce delays. Even if vertiports could be financed through a combination of AIP funds, PFCs, and landing fees, operators will still need to access capital markets to provide financing. In turn, the financial community will need assurances about the potential economic viability of CTR service.

Developing the air infrastructure for a CTR system will be the responsibility of FAA. Existing studies show that accommodating CTR in the air traffic control (ATC) system is feasible and will not present a major cost burden. This research also shows that CTR operations will not have an adverse impact on the ability of the ATC system to handle conventional aircraft operations.

Potential CTR operators will need to see the prospect of profitable operations before investing in these aircraft. This will require that CTR technology be enhanced to produce a safe and reliable vehicle. Operators also will require that air and ground infrastructure be developed for initial CTR operations, and that planning and financing for a vertiport network in various corridors is underway. This requires that CTR environmental characteristics allow operations close to passenger origin and destination demand that is a key factor in the economic viability of CTR. Operators are also likely to require that any questions about passenger acceptance of CTR aircraft be resolved prior to investing in new aircraft.

12.2 Opportunities for Cooperation and Cost Sharing

Current policy calls for industry cost sharing in NASA aeronautics R&D programs. The Civil Tiltrotor Development Advisory Committee (CTRDAC) also found that Government/industry cost sharing should be built into an enhanced CTR research program. The CTRDAC also proposed that the level of industry cost sharing increase as CTR technology moves closer to market introduction. The funds to launch a CTR production program, however, would be entirely the responsibility of industry.

The funds for ground infrastructure planning could come from both local and Federal funds. Planning grant funds for vertiports could be made available under AIP for aviation system planning. Funding for the improvement of existing facilities and the development of new vertiports should also come from those who benefit from a CTR transportation system and take into account existing financing mechanisms for aviation infrastructure. The operating costs of these facilities could be paid for with landing fees paid by CTR operators as shown in the CTRDAC financial analysis. In addition, a vertiport could produce non-aeronautical revenues from automobile parking and from concessions.

Investment funds for vertiports are likely to come from AIP, PFCs, and bond financing secured by landing fee revenues. The CTRDAC recognizes that AIP may undergo a significant restructuring. However, the CTRDAC also recognizes that CTR operations will produce substantial incremental passenger ticket tax revenues even after allowing for the reduction in ticket taxes from diversions from conventional air operations. As such, vertiports could be made eligible for AIP entitlement funds based on passenger enplanements. As noted above, the financial community will need assurances that there is a reasonable prospect for repayment before it lends money for vertiport development. There may be a need for a guarantee of financing for the early phases of vertiport development in order to access the bond market.

12.3 Establish a Public/Private CTR Partnership

As a new transportation system, no existing organization is charged with coordinating activities related to CTR. Because of the many decisions and actions required by diverse parties to implement a CTR transportation system, the CTRDAC recommends the establishment of a public/private partnership to undertake the necessary coordination. This body would be charged with developing an overall research and implementation plan, conducting detailed CTR network studies, monitoring the CTR R&D program, and providing recommendations to Congress on whether the CTRDAC proposed schedule or funding for R&D and implementation should be adjusted, redirected, or terminated. With the uncertainties and risks surrounding development of a new CTR transportation system, there should be explicit provisions in place to coordinate and redirect the activities of all parties.

The public/private partnership could be structured by FAA. There would be a need to provide the partnership with a modest level of Federal funding of under $1 million per year. It would bring together the activities of FAA, NASA, state and local governments, airport interests, and aircraft manufacturers to coordinate the recommended study of CTR networks and to coordinate CTR research and development. For example, the CTRDAC has recommended that the CTR be included in the exploration of capacity improvement options for short-haul transportation corridors.

It is expected that state and local governments, airports, and industry would bear their own costs for participating in the partnership.

12.4 CTR as a Capacity Enhancing Option

There are various options available to help meet the growing demand for short-haul transportation in intercity corridors. The Department of Transportation is charged with assessing national transportation system requirements and should include CTR among the options considered to meet national transportation needs. Other options might include:

- Building new airports or expanding existing aviation facilities
- Improving ATC system capacity
- Developing new higher speed rail systems
- Improving highway systems, building expanded roadway capacity, and using intelligent transportation systems
- Relying on demand management to ration existing capacity

Several of these alternatives, including CTR, will likely be required to satisfy the growing demand for intercity passenger travel. It is important to find the most cost-effective and environmentally compatible solutions for each transportation corridor. These are not likely to be the same for every U.S. transportation corridor.

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13.0 Findings

The Civil Tiltrotor Development Advisory Committee (CTRDAC) finds that:

1. CTR is technically feasible and can be developed by U.S. industry.

- Experience with the XV-3, XV-15, and the V-22 provides a starting point for development of a safe and environmentally acceptable CTR for commercial passenger service, but additional R&D is needed before industry can make a production commitment for a commercial passenger vehicle.
- A smaller CTR could be developed for the corporate and utility market using existing CTR technology.
- Energy consumption and emissions do not appear to be discriminators against CTR environmental feasibility but may loom larger for all modes of transportation in the future.
- Operations in compliance with rigorous certification standards in a controlled operating environment are central to aviation safety. A CTR used in scheduled air carrier service is expected to have a safety record comparable to conventional air service.
- CTR flight characteristics and flight deck design should allow direct transition training to CTR for instrument-rated pilots from either the fixed-wing or helicopter communities.
- System condition and usage monitoring technology and the use of a flight operations quality assurance (FOQA) program can be expected to greatly enhance the safe operation of CTR and to reduce maintenance costs and ground support.

2. Successful civil tiltrotor (CTR) introduction depends on overcoming significant uncertainties and risks.

- Decisions to manufacture CTRs, develop air and ground infrastructure, and operate services are interdependent and highly sensitive to evolving findings and perceptions concerning potential demand, commercial viability, infrastructure financing mechanisms, and community acceptance.
- Although the estimated demand for CTR aircraft seems sufficient to satisfy the minimum requirements of manufacturers to pursue CTR development activities, it is unlikely that a U.S. manufacturer would launch a CTR program without further development of the technology because of the increased research and development (R&D) expense and the technical and market risks involved.
- The commercial viability of CTRs operated in airline service depends on fares charged by conventional airlines and their competitive response to the introduction of CTR service. It also depends on siting vertiports in favorable locations, as well as CTR acquisition and operating costs.

3. Vertiport siting is a critical factor in CTR system viability. Planning for CTR infrastructure should be integrated into national and local transportation system planning.

- In the four U.S. corridors studied, most of the candidate cities would be well served by two vertiports. Larger cities may benefit from three or four vertiports.

• The overall costs associated with vertiport networks are low when compared to the costs of new airports, new runways, or improved rail infrastructure.

• Preliminary analysis indicates that about half the vertiports could be located at commercial service airports located near city centers or at general aviation airports located in suburban areas.

• Community acceptance of vertiports will be central to developing a CTR transportation infrastructure. Essential considerations include noise reduction to minimize land-use, safe operation and community perception of safe operations, and recognition by the community of the public benefits of CTR.

• The total cost for vertiports for the four major U.S. corridors is estimated to be approximately $666 million. A start-up vertiport system could be launched for approximately $68 million. These costs do not include noise and environmental mitigation.

• A substantial investment in off-airport infrastructure will be required. Access to private capital markets will be needed to provide funding for construction. Public ownership is expected for vertiports that support air carrier operations.

• Vertiports need to be established in meaningful networks. This poses a challenge because success depends on gaining the simultaneous approval of many local governments.

• The success of CTR depends heavily on the capability of the Federal Aviation Administration (FAA) to provide air traffic control (ATC) services in ways that allow CTR to operate efficiently. The advent of Global Positioning System (GPS) and automatic dependent surveillance (ADS) should provide the ATC system with the capacity to handle CTR efficiently without causing delays to other aircraft in both the en route and terminal areas.

• Vertiports will require specific design criteria. The FAA Advisory Circular "Vertiport Design" needs to be revised to reflect advances in research and development and the growing understanding of CTR capabilities.

• Current methods and metrics used to assess aircraft noise around airports may not be adequate for land use planning and regulation development for vertiports.

• A flight demonstration program is essential in evaluating community acceptance of vertiports and CTR overflights.

• Operational characteristics contribute much to external noise, emissions, safety, and thus to community and passenger acceptance. Procedures must be developed to minimize noise signatures and the likelihood of accidents that could injure members of the community or cause property damage.

• Establishing CTR infrastructure will require the cooperation and coordination of diverse institutional elements. No one party has total jurisdiction, control, or the decision making power to implement, direct, or mandate the program unilaterally.

4. Under certain assumptions, a CTR system could be economically viable and operate profitably without Government subsidies.

• CTR would attract a significant number of travelers who value reduced overall trip time. In most markets, CTR fares will likely need to be substantially higher than prevailing airfares to cover projected CTR per passenger costs due to higher initial acquisition and operating costs. However, CTR travel typically results in lower overall travel times, including access/egress time, resulting in a competitive trip time cost trade-off for many passengers.

• CTRs have the potential to be operated profitably in highly traveled corridors and produce an acceptable return on investment for manufacturers, CTR operators, and vertiport providers.

• CTR service is more likely to be financially viable in the Northeast and some Midwest markets due to higher prevailing airfares in these markets. CTR service in markets where existing airfares are low, such as the West Coast and Southwest corridors, would be less financially successful.

• CTR services are estimated to divert approximately 11 percent of air passengers in the four U.S. corridors. These new CTR passengers would be primarily business travelers who previously used conventional jet services.

• The worldwide demand for 40-passenger CTR aircraft is estimated to range from 1,160 to 1,600 vehicles in the year 2010, including more than 400 in the North American market. The projected selling price is $18.5 million per unit. A higher selling price could result in a smaller market. If manufacturing costs are compatible with an $18.5 million price, a CTR program would have a real rate of return on cash flow of 12 percent, assuming 500 units could be sold over 10 years.

• Operation of CTRs in the four U.S. corridors studied would provide operators with a real rate of return of approximately 11 percent at a CTR selling price of $18.5 million. A higher rate of return can be achieved, but at the expense of higher CTR costs and fares. This would result in lower ridership and reduced societal benefits.

5. CTR could produce significant societal benefits.

• By reducing conventional aircraft operation, CTRs could reduce congestion and resulting delays at existing airports and might reduce total investment required for other transportation infrastructure.

• CTR can produce significant societal benefits, primarily from alleviating congestion at capacity-constrained airports.

• A CTR developed in the U.S. would create jobs and improve the balance of trade.

• Offsetting these benefits, in part, are the increased fuel consumption and engine emissions of the CTR compared to conventional airplanes and other intercity transportation modes.

• Only a small portion of these benefits accrue to an airline operating CTRs. Therefore, CTR societal benefits are not expected to be a consideration in airline decisions to acquire CTRs.

• Using the lower bound of possible annual delay benefits, the net present value (NPV) in 1995 of the societal benefits (delay reduction) and costs (increased emissions) of CTR operations in the four corridors studied total approximately $1.86 billion.

• Overall, when considering all private and social benefits and costs, and how they occur over time, the CTR program has an estimated real rate of return to society of as much as 16 percent.

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14.0 Recommendations

The Civil Tiltrotor Development Advisory Committee (CTRDAC) recommendations include:

1. Create a public/private partnership to address civil tiltrotor (CTR) institutional, infrastructure, and coordination issues.

- The Federal Aviation Administration (FAA) should take the lead in coordinating activities and facilitating necessary interdependent decisions. It would lead a public/private partnership established to create an overall plan covering all critical elements needed to conduct research and establish a CTR short-haul transportation system. This plan should be designed to minimize capital expenditures until a production decision is made. It would also provide specific criteria for periodic evaluations to continue, redirect, or terminate the plan. Due to cost sharing, the public/private partnership would entail only a modest outlay of Federal funds.

- A CTR network study involving manufacturers, the FAA, and local governments should be developed for one promising U.S. corridor. The study should include the identification of specific vertiport sites to determine operational requirements and improve demand analysis. A zone-specific passenger origin/destination travel demand analysis should be performed incorporating travel time sensitivity. This analysis must use data comparable across metropolitan areas. Finally, the active cooperation of local planning bodies must be sought to acquire necessary input data for vertiport locations, CTR operations planning, and general issues related to community acceptance of CTR.

- Work should begin on site identification and preliminary planning for vertiports. This includes planning for modifications to existing facilities for start-up, including selecting airports and heliports, as well as development planning of new vertiport facilities for a mature CTR system.

- Local and regional transportation planning organizations should be encouraged to include vertiports in local/regional transportation system planning.

- Mortgage insurance incentive programs for local compatible land-use planning in the vicinity of airports/vertiports should be restored. These programs, administered by the Departments of Housing and Urban Development and Veterans Affairs, helped to discourage incompatible development in the vicinity of airports. In the absence of these programs, investments at airports are at risk from encroachments that may prevent the facilities from delivering the full benefits that would otherwise be possible.

2. Proceed with an integrated CTR aircraft and infrastructure research, development, test, and demonstration program.

- The approximately $600 million cost of CTR research and development should be shared by Government and industry.

- The FAA and the National Aeronautics and Space Administration (NASA), in coordination with the public/private partnership, should develop a phased research program that can be accelerated or terminated at set points as results warrant.

- Specific CTR-related research should be completed before the year 2003 addressing the following:
  - A low-noise rotor design and the operational flight procedures to minimize noise.
  - The development of better technical tools and metrics for calculating CTR noise lev-

els and for predicting community response to CTR operations to guide planning for vertiports and the associated infrastructure system.

- Engine and transmission system design for affordable, near instantaneous engine response to contingency power ratings following a single engine failure.
- Designs for power-off control and landing capabilities to ensure operational safety that meets or exceeds current standards for transport aircraft, including rotorcraft.
- System condition and usage monitoring technology in areas peculiar to the CTR configuration.
- Human factors for flight deck design, including displays and controls, emergency procedures, and situational awareness.
- Rotorwash and wake vortex measurements to assess their impact on ground operations and other aircraft to be used in developing procedures to minimize or avoid that impact.
- Internal aircraft noise.

• General aeronautical research of importance to CTR should be monitored closely. This includes:

- Composites and advanced manufacturing techniques.
- Icing removal/prevention systems.
- Fly-by-wire technology with an emphasis on failure modes analysis and certification criteria for reliability.

• A program of flight tests should be conducted to verify noise-reduction technology, flight characteristics, air traffic control (ATC) procedures, and airspace designs. Subsequent flight demonstrations should be conducted in and around selected cities and operational environments to assess community acceptance, environmental effects, and to gain operational experience.

• Analyses should be undertaken to produce more accurate estimates of actual energy emissions of CTR per seat-mile and possible gains in total efficiency under different scenarios of use and local traffic impact.

• Infrastructure research and development work is also required. This would be sponsored by the FAA and would require $4 million per year during the years 1997 through 2003. It would include:

- CTR Terminal Instrument Procedures (TERPS), including Category 2 and 3 operations.
- Designing and implementing airspace around vertiports.
- ATC procedures.
- Aircraft separation standards on approach to vertiports.
- Updating the Vertiport Design Advisory Circular (AC), including land-use planning, capacity, lighting and marking, touchdown and lift-off (TLOF) instrument flight rules (IFR) separation, and separation standards for TLOFs/final approach and takeoff areas (FATO)/taxiways.
- Revision of Code of Federal Regulations, 14CFR77, "Objects Affecting Navigable Airspace", for vertiports.
- Training requirements.

3. Continue and accelerate work on regulatory and certification issues.

• The FAA should review and revise current operations certification regulations that would be applicable to a CTR in scheduled air carrier service to provide the highest level of safety.

• A plan for changes to the ATC system in potential CTR corridors should be developed.

- Safety and environmental research and development related to CTR regulatory requirements should be conducted.

- Additional research into one-engine inoperable regulatory standards for CTR is required to reduce the risk of failure or delay in the initial CTR certification activity.

- FAA Advisory Circular 150/5050-6, "Airport - Land-use Compatibility Planning" should be revised and reinstated. This AC should specifically address vertiports and tiltrotors.

- FAA Advisory Circular "Vertiport Design" should be revised to address land use, capacity requirements, and airspace requirements for low-visibility Global Positioning System (GPS) procedures. Revisions should also address the results of recent research in vertiport capacity, lighting and marking, TLOF IFR separation, separation standards for TLOFs/FATO/taxiways, and rotorwash/wake vortices.

- FAA should develop standardized guidelines for implementing and designing airspace at vertiports when the facilities are underneath existing controlled airspace and for assessing impacts on local and regional airspace if controlled airspace is located around vertiports.

- 14CFR77, "Objects Affecting Navigable Airspace" should be revised to address CTR and vertiport issues.

- The FAA should develop establishment criteria for ATC towers appropriate for CTR and vertiports.

4. The Department of Transportation should initiate a multimodal study of options, including CTR, for increasing intercity transportation capacity.

- The Department of Transportation should take the lead in defining solutions, including the use of CTR, to overcome deficiencies in intercity passenger transportation capacity.

- CTR should be included in analyses of transportation improvements for specific heavily traveled corridors.

- All options, including CTR, should be examined to determine which solution or combination of solutions are most appropriate in economic, environmental, safety, and other dimensions in specific transportation corridors.

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15.0 Acronyms

A/E	Access/egress
AC	Advisory Circular
ADS	Automatic Dependent Surveillance
AIAA	Aerospace Industries Association of America
AIP	Airport Improvement Program
ASM	Available Seat-mile
ATC	Air Traffic Control
CFR	Code of Federal Regulations
CO	Carbon Monoxide
CRAF	Civil Reserve Aircraft Fleet
CTR	Civil Tiltrotor
CTRDAC	Civil Tiltrotor Development Advisory Committee
dB	Decibel
dBA	A-weighted decibels
DER	Designated Engineering Representative
DGPS	Differential GPS
DNL	Day-night-level
DoD	Department of Defense
EMD	Engineering and Manufacturing Development
EMS	Emergency Medical Service
EUROFAR	European Future Advanced Rotorcraft
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FATO	Final Approach and Takeoff Area
FBW	Fly-By-Wire
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FMEA	Failure Modes and Effects Analysis
FOQA	Flight Operations Quality Assurance
FSD	Full-Scale Development
FTA	Federal Transit Administration
GA	General Aviation
GAO	Government Accounting Office
GPS	Global Positioning System
HC	Hydrocarbon
HDR	High Density Rule
HUD	Housing and Urban Development
HUMS	Health and Usage Monitoring Systems
ICAO	International Civil Aviation Organization
ICDS	Interconnect Drive Shaft
IFR	Instrument Flight Rules
IRR	Internal Rate of Return
ISTEA	Intermodal Surface Transportation Efficiency Act
LAAS	Local Area Augmentation System
LH	Line-haul

MITI	Ministry of International Trade & Industry
MPO	Metropolitan Planning Organization
MSA	Metropolitan Statistical Area
NASA	National Aeronautics and Space Administration
NASPAC	National Airspace System Performance Analysis Capability
NM	Nautical Mile
NPRM	notice of proposed rulemaking
NPV	Net Present Value
NRS	National Resource Specialist
O&M	Operation and Maintenance
O/D	Origin-to-destination
OEI	One Engine Inoperable
PFC	Passenger Facility Charge
R&D	Research and Development
RPM	Revenue Passenger Miles
TERPS	Terminal Instrument Procedures
TLOF	Touchdown Lift-off Surface
VA	Veterans Affairs
VDTR	Variable Diameter Tiltrotor
VFR	Visual Flight Rules
WAAS	Wide Area Augmentation System

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